# Aortic Stenosis
## Different Variants

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## DISCLOSURE

**Relevant Financial Relationship(s)**

None

**Off Label Usage**

None

# 03/10/2005

# Severity of Aortic Stenosis

## Severe Aortic Stenosis

### Area Gradient Match

| | Mean Gradient (mmHg) | Valve Area ($cm^2$) | Valve Velocity (m/sec) |
|---|---|---|---|
| Mild | <25 | >1.5 | 2-2.9 |
| Moderate | 25- 40 | 1.0-1.5 | 3-3.9 |
| Severe | >40 | <1.0 | > 4.0 |

iAVA < 0.6 $cm/m^2$

Nishimura, et al. Circulation, 2014
Bonow RO, et al. Circulation, 2008

# Severity of Aortic Stenosis

## Severe Aortic Stenosis

### Area Gradient Mismatch

| | Mean Gradient (mmHg) | Valve Area ($cm^2$) | Valve Velocity (m/sec) |
|---|---|---|---|
| Mild | <20 | >1.5 | 2 - 2.9 |
| Moderate | 20- 39 | 1.0-1.5 | 3 - 3.9 |
| Severe | >40 | <1.0 | > 4.0 |

iAVA < 0.6 $cm/m^2$

Nishimura, et al. Circulation, 2014
Bonow RO, et al. Circulation, 2008

# Severity of Aortic Stenosis

## Severe Aortic Stenosis

### Reverse Area Gradient Mismatch

| | Mean Gradient (mmHg) | Valve Area ($cm^2$) | Valve Velocity (cm/sec) |
|---|---|---|---|
| Mild | <20 | >1.5 | 2 – 2.9 |
| Moderate | 20-39 | 1.0-1.5 | 3 – 3.9 |
| Severe | >40 | < 1.0 | > 4.0 |

Nishimura, et al., Circulation 2014
Bonow RO. et al. Circulation. 2008

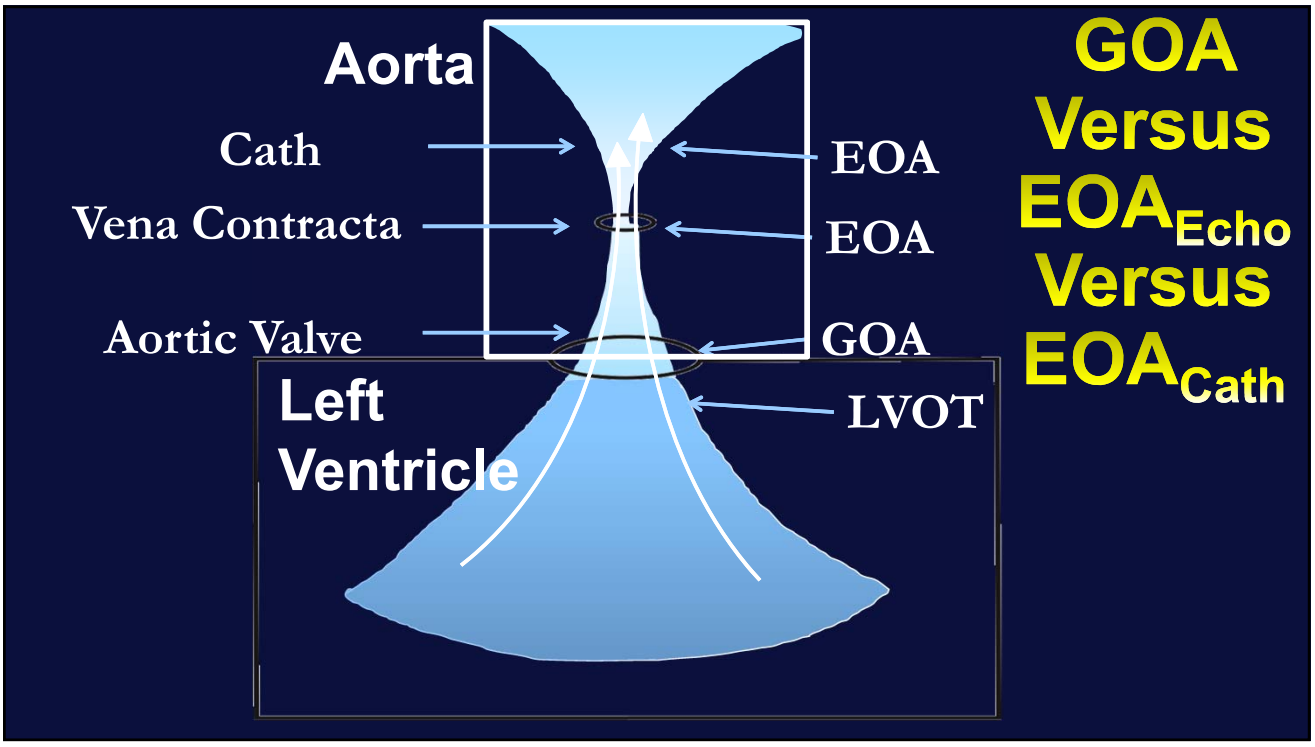
# Aortic Stenosis

## Determining the "True" Severity

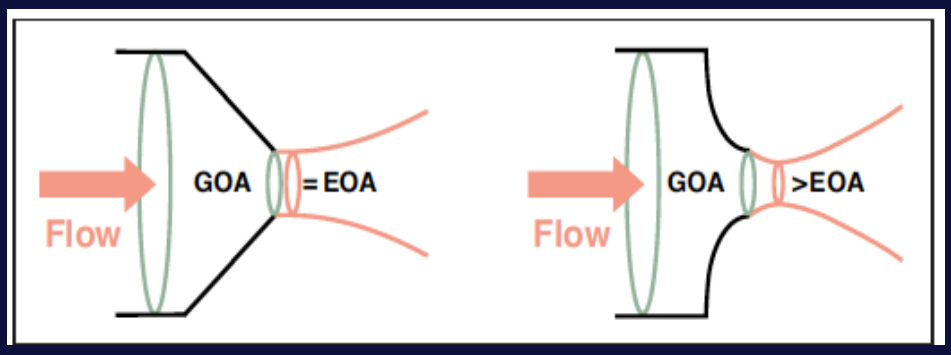
## Measurement Errors Must be Excluded

## Topics of Discussions

- GOA Vs. EOA
- Doppler Vs. Catheter
- Factors affecting Gradient
- Area/Gradient Mismatch
- Reverse Area Gradient Mismatch




## GOA Versus EOA

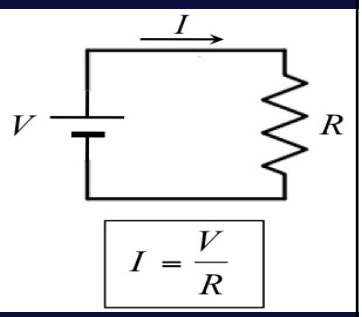



B

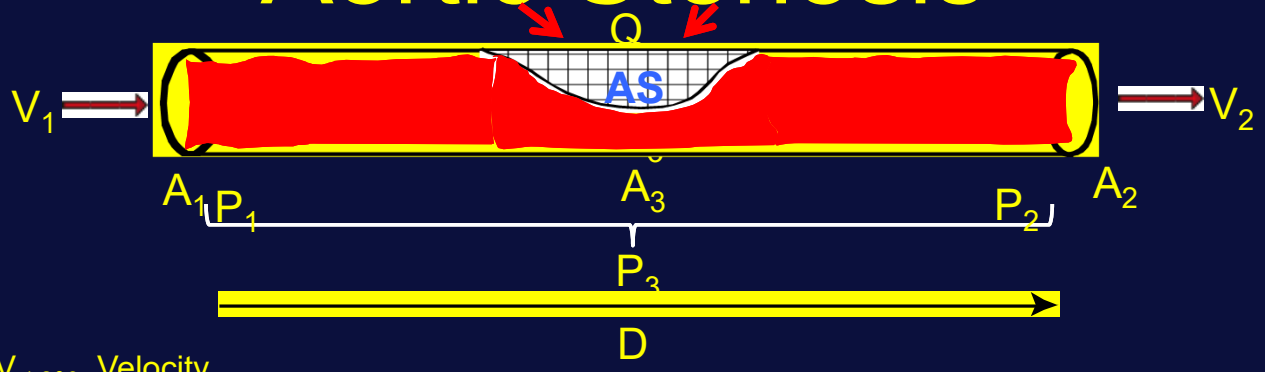
**GOA: Planimetry**
**EOA: Continuity Equation/Gorlin**
**Coefficient of Contraction: EOA/GOA**

# Evangelista Torricelli
1608-1647


# Georg Simon Ohm
1789-1854




# Aortic Stenosis



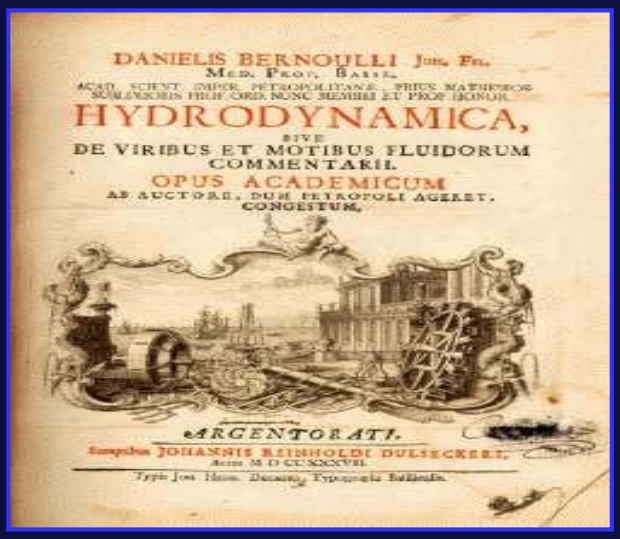

| | |
|---|---|
| $V_{1,2\&3}$ | Velocity |
| $A_{1,2\&3}$ | Area |
| Q | Flow |
| R | Resistance |
| $P_{1,2\&3}$ | Pressure |
| D | Distance |

**Catheterization: Flow Q = $\frac{\Delta \text{ Pressure}\uparrow}{\text{Resistance}\uparrow}$**

**Doppler: Flow Q = Area x Velocity** (Area ↓, Velocity ↑)

# Daniel Bernoulli

**1700-1782**




# Bernoulli Equation


$$P1-P2 = \frac{1}{2}\rho(V_2^2-V_1^2) + \rho\int^{max}(dv/dt) * ds + R(\mu)$$

*Convective acceleration*

*Flow acceleration*

*Short Tube Non-Laminar Acceleration*

*Viscous Friction*

P1&V1= proximal to obstruction
P2&V2= distal to obstruction
ρ=mass density of blood
R=viscous resistance
μ = viscosity

# Pressure Recovery

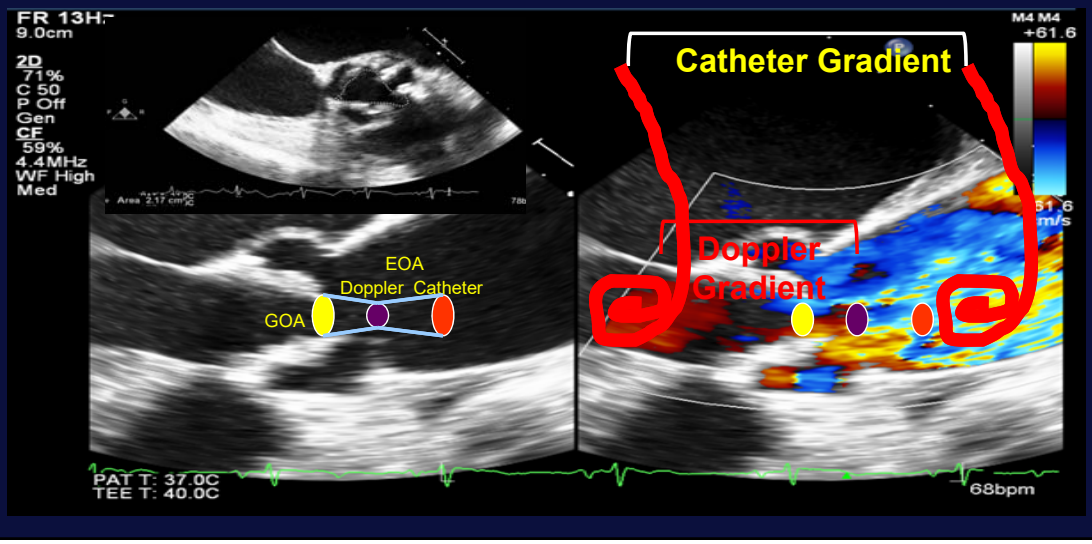
**Pressure Energy In Ventricle**

**Doppler Gradient: $\Delta P_{max}$**

**Pressure Recovery** | Doppler/Catheter Concordance | **Pressure Gradient**

**Catheter Gradient: $\Delta P_{net}$**

# Doppler versus Catheter Area and Gradient Assessment



# Upcoming Concepts

- For a given AV GOA
  - The Gradient can be variable
  - The EOA can be variable
  - (Derived from gradient)
  - The Area and Gradient may not match
  - The Doppler and Catheter measures may not match

# Doppler Aortic Valve Area Assessment

DIAGNOSTIC METHODS
DOPPLER ECHOCARDIOGRAPHY

1985

**Noninvasive estimation of valve area in patients with aortic stenosis by Doppler ultrasound and two-dimensional echocardiography**

TERJE SKJAERPE, M.D., LARS HEGRENAES, M.D., AND LIV HATLE, M.D.

- Described in 30 subjects; 14 had significant AR
- Compared only to Fick and single plane CO angiography

# Doppler Gradient Assessment

*British Heart Journal*, 1978, **40**, 131-140

Noninvasive assessment of pressure drop in mitral stenosis by Doppler ultrasound

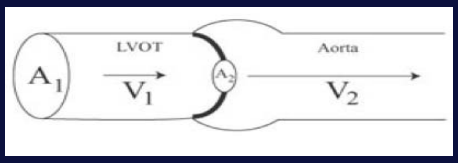
L. HATLE, A. BRUBAKK, A. TROMSDAL, AND B. ANGELSEN

*From Section of Cardiology, Medical Department, University Hospital, 7000 Trondheim; and Division of Engineering Cybernetics, The Norwegian Institute of Technology and Division of Automatic Control at the Foundation of Scientific and Industrial Control at the University of Trondheim, 7000 Trondheim, Norway*

- Described in 10 subjects
- Extrapolated to aortic valve

# Doppler Aortic Valve Gradient Assessment

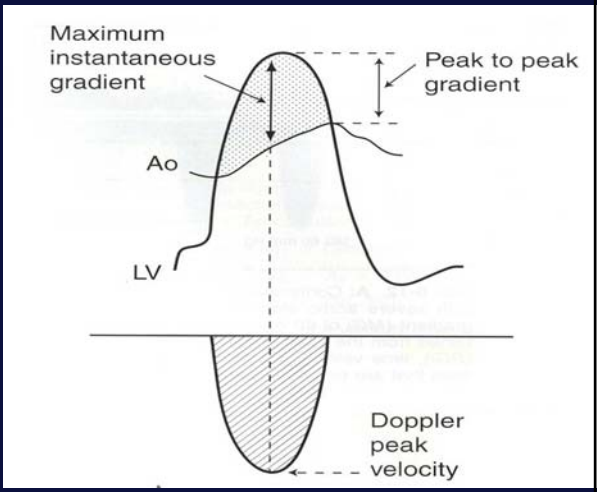
- Doppler
  - MIG = $4V_2^2 - 4V_1^2$
  - MIG = $4V_2^2$
- Use MIG = $4V_2^2 - 4V_1^2$
  - $V_1 > 1.5$ m/second
  - $V_2 < 3$ m/second




B

# Doppler versus Catheter Gradient Assessment

- Catheterization
  - Peak to Peak
  - $P_{mean\ Catheter}$
- Doppler
  - MIG $(4V_2^2 - 4V_1^2)$
  - $P_{mean\ Doppler}$
- MIG always > PPG
- $P_{mean\ Doppler} - P_{mean\ Catheter} = P_{rec}$




B

# Not Pressure Recovery

- LV Pressure: Peak 200 mmHg
- Aortic Pressure: Peak 150 mmHg
- Cath Peak to Peak: 50 mmHg
- Doppler Velocity: 4.5 m/second
- Doppler Maximum Instantaneous Gradient: Peak: 81

## Pressure Recovery

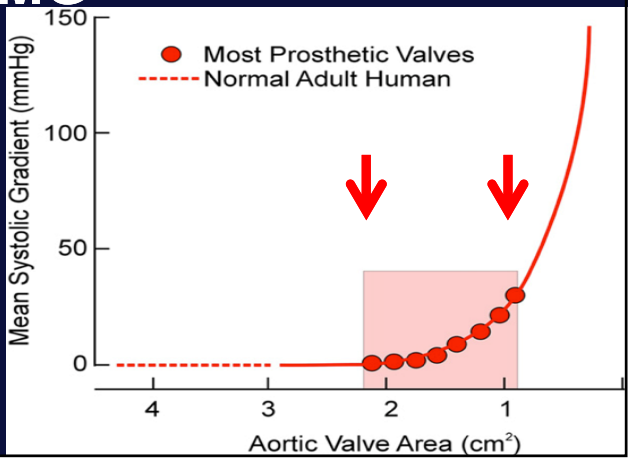
- Catheterization Gradient = Mean 40 mmHg
- Doppler Mean Gradient = 50 mmHg
- Pressure Recovery = 10 mmHg

# Gradient Determinants

- Area
- Flow
- Jet Eccentricity
- Aortic root diameter
- Global LV afterload

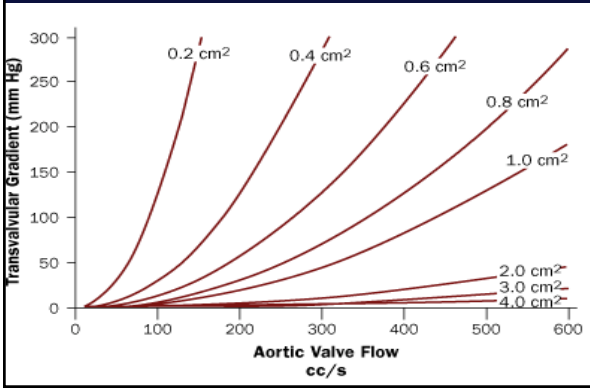
# Gradient Determinants
## Area

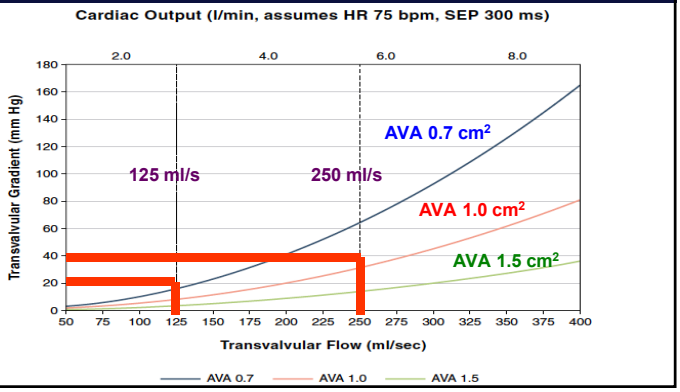
- There is an *inverse* quadratic relationship: Area & MG
- $\Delta P = Q^2/(K \times EOA^2)$

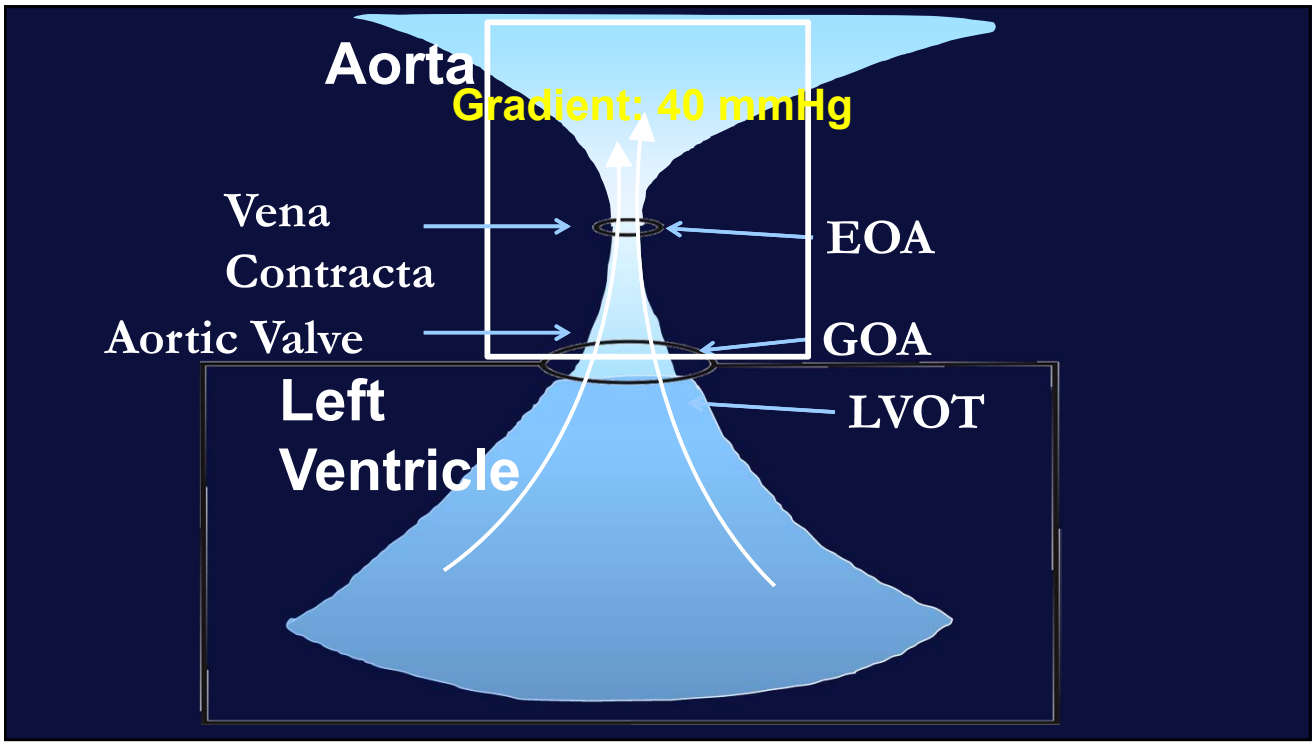


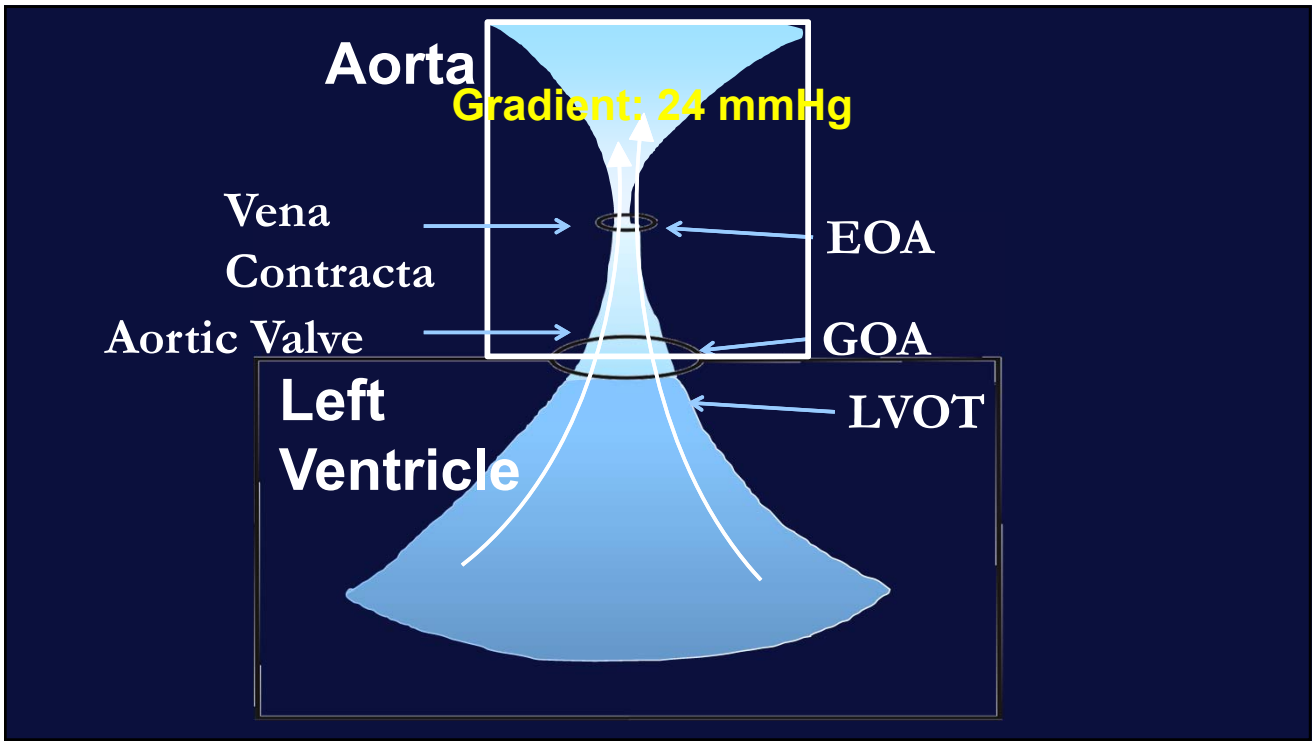

# Gradient Determinants
## Flow

- *Direct* quadratic relationship: Flow & MG
- Low Flow: SVI < 35ml/m²
- Low Flow rate < 200-250 ml/s



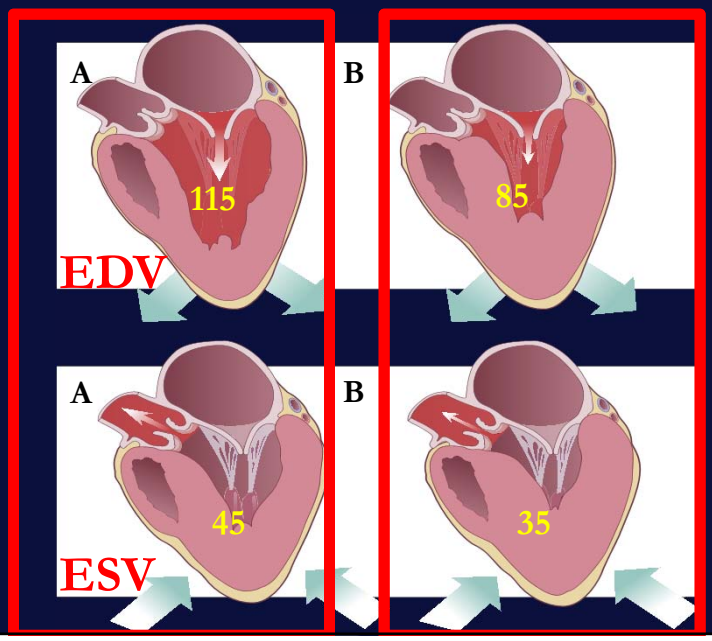

Aorta
Gradient: 40 mmHg
Vena
Contracta
EOA
Aortic Valve
GOA
Left
Ventricle
LVOT


Aorta
Gradient: 24 mmHg
Vena
Contracta
EOA
Aortic Valve
GOA
Left
Ventricle
LVOT

# Flow ≠ EF

**A:** EDV = 115, ESV = 45,
SV= 115-45 = 70 ml
BSA = 1.79
EF = 70/115 = 60%
SVI = 39 ml/m$^2$

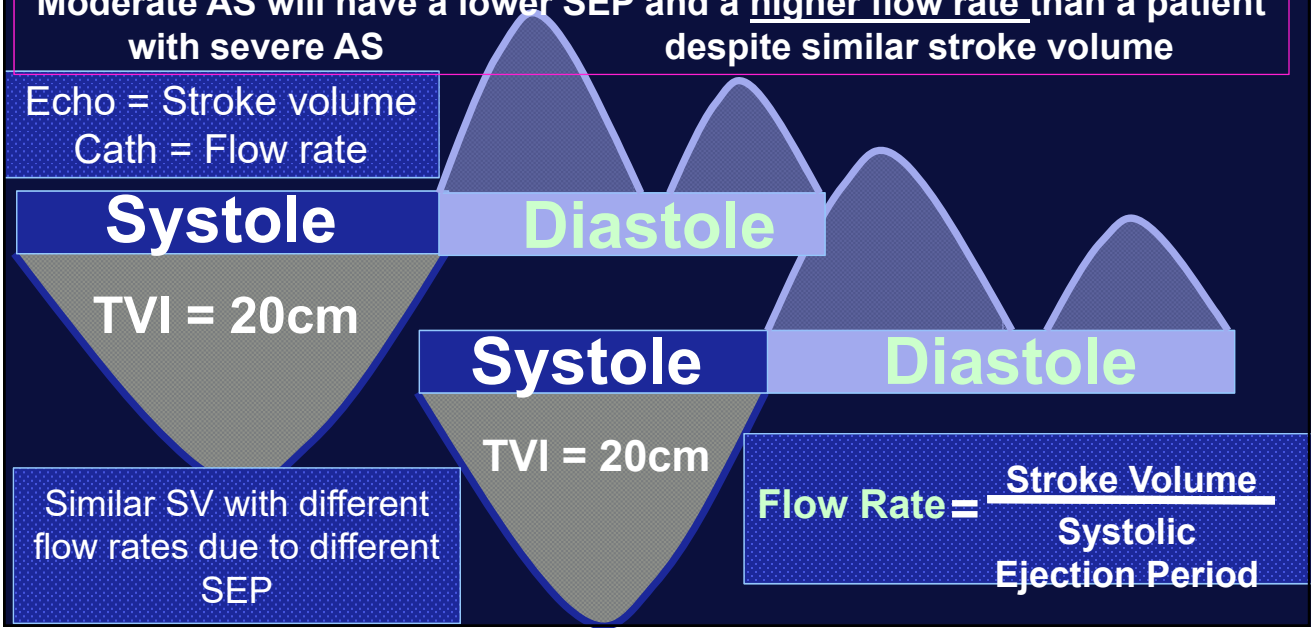
**B:** EDV = 85, ESV = 35,
SV= 85- 35= 50 ml
BSA = 1.79
EF = 50/85 = 60%
SVI = 28 ml/m$^2$




# Stroke Volume ≠ Flow Rate

**Moderate AS will have a lower SEP and a higher flow rate than a patient with severe AS despite similar stroke volume**

Echo = Stroke volume
Cath = Flow rate



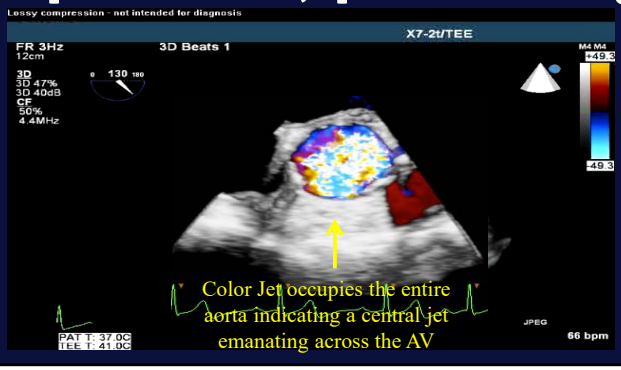

Similar SV with different flow rates due to different SEP

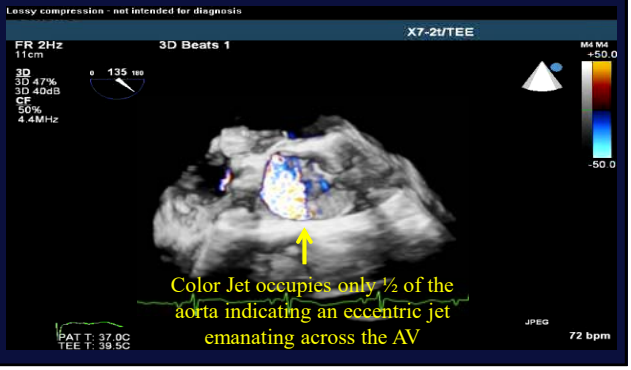
$$\text{Flow Rate} = \frac{\text{Stroke Volume}}{\text{Systolic Ejection Period}}$$

# Gradient Determinants
# Eccentric Jet

- Eccentric Jet Up to 30° ➔ Higher Gradient.
- Jet squeezed against aorta. More pressure loss & less pressure recovery, **Bicuspid valves/radiation**

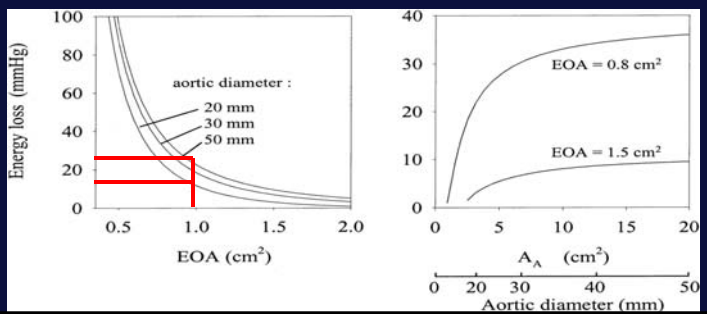
⑩ ↑Vel 0.7 m/s, ↑MG 23 mmHg, ↓ EOA 0.2



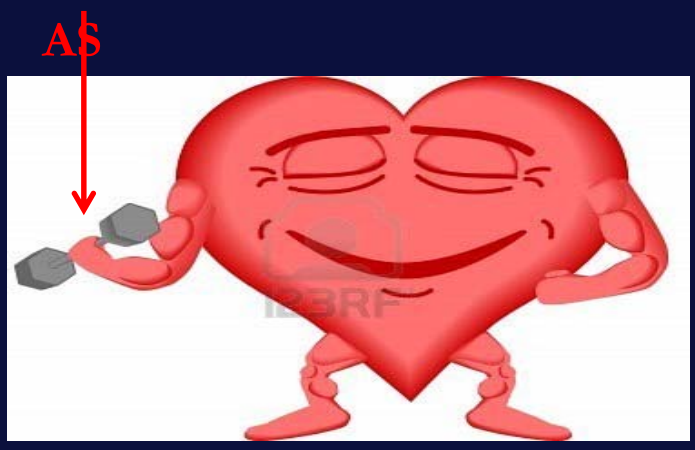




# Gradient Determinants
# Aortic Root Diameter

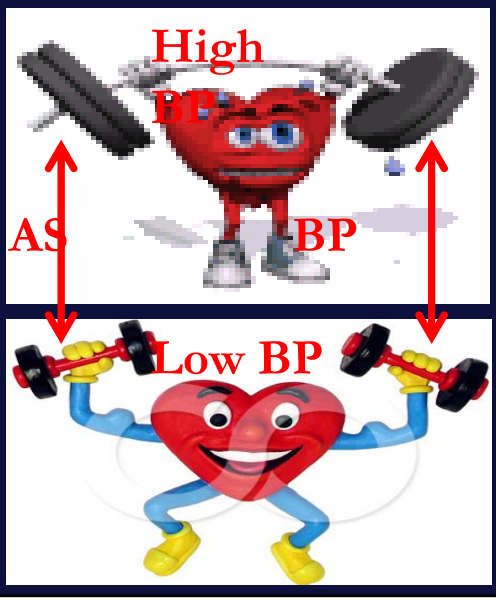
- The smaller the aortic root, the less energy loss, the more the pressure recovery, the lower the catheter gradient.
- This effect plateaus at a diameter of STJ 30 mm (area 7 $cm^2$)



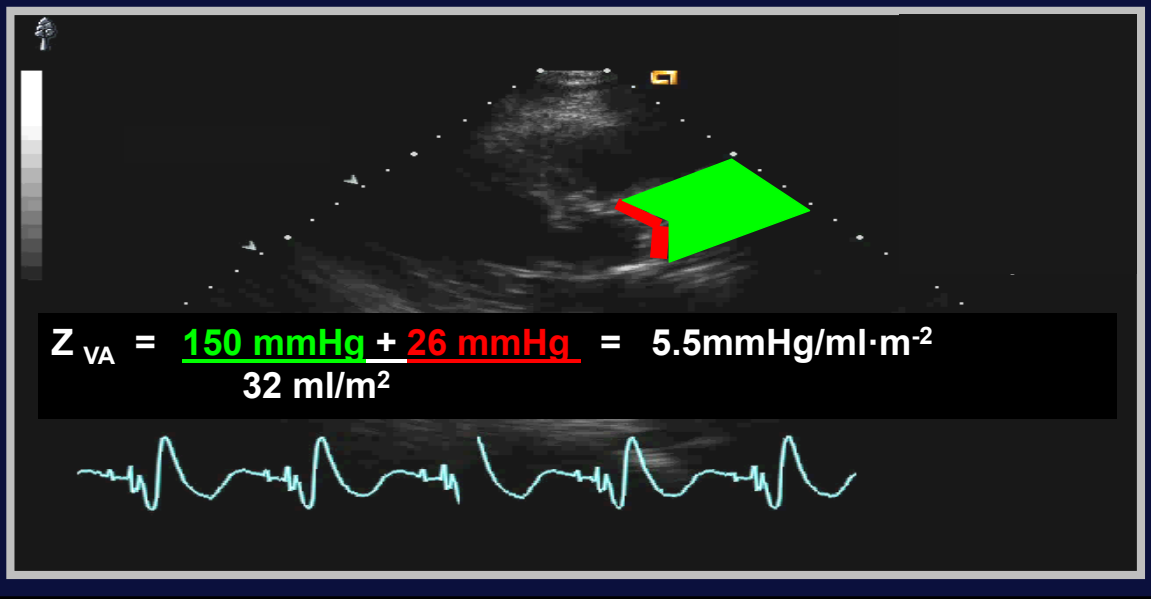
# Global Left Ventricular Afterload

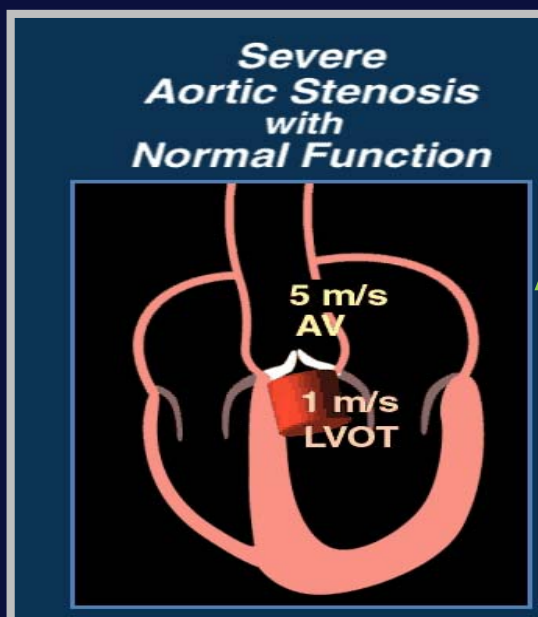



Moderate AS and low compliance =
Severe AS and normal compliance




# Global Left Ventricular Afterload






Area Gradient Match

Normal Ejection Fraction
Normal SV & Flow Rate
AVA<1cm$^2$
$\Delta P_{mean}$>40mmHg

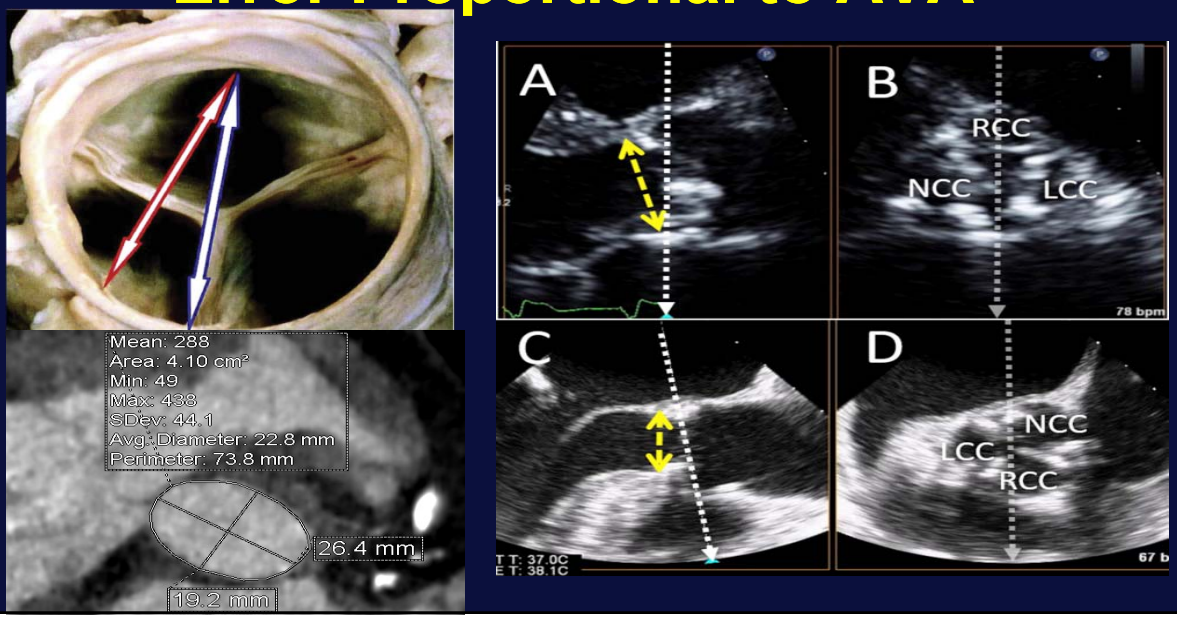
Courtesy Heidi Connolly

# Aortic Stenosis
## Area/Gradient Mismatch

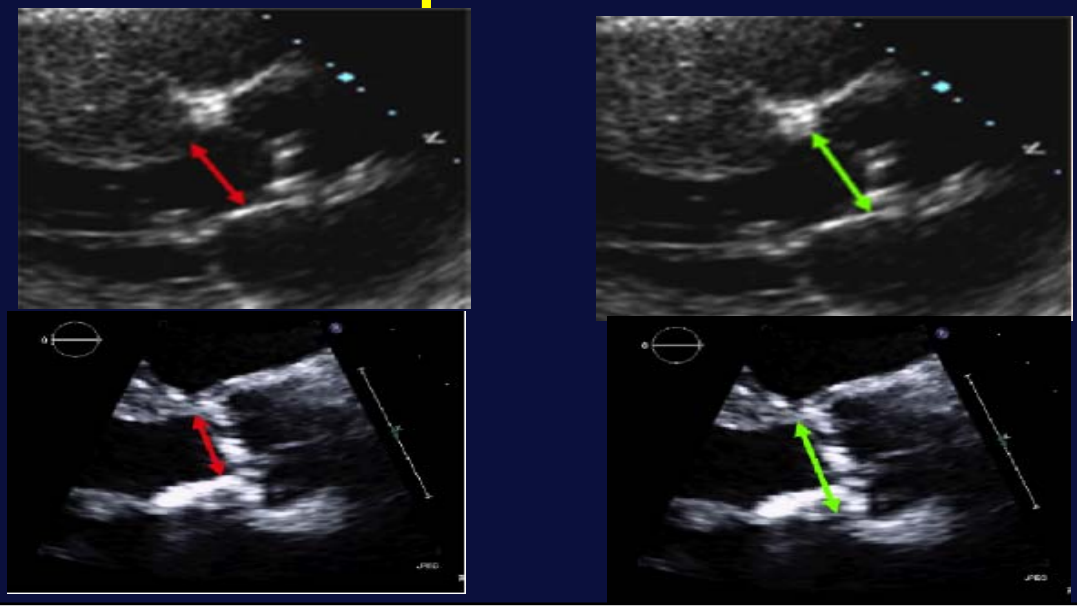
# Area Gradient Mismatch

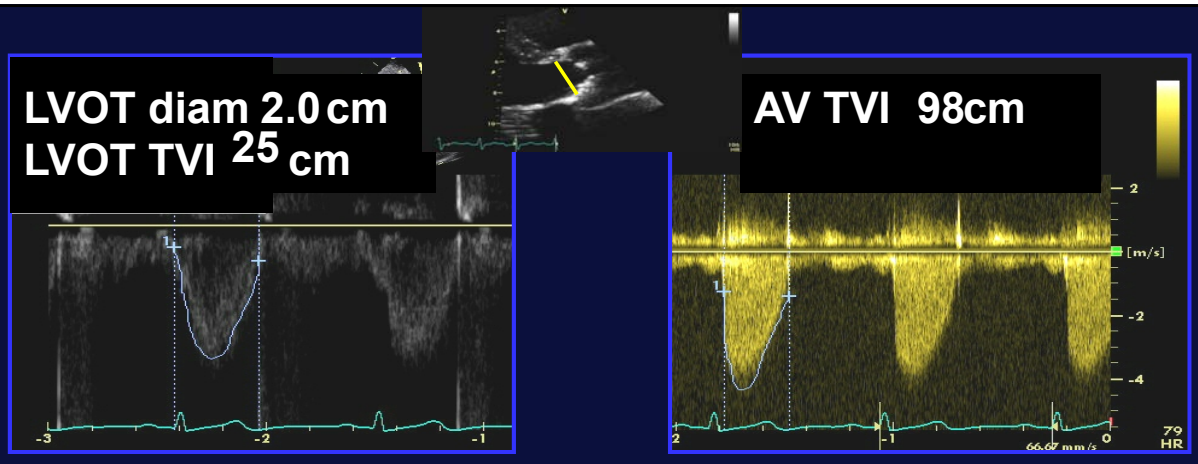
- Measurement Error
- Assumption Error
- Low Flow/Low Gradient/Low EF area/gradient mismatch
- Low Flow/Low Gradient/Normal EF area/gradient mismatch

## Measurement Errors: LVOT D Error Proportional to AVA



# Measurement Errors: LVOT D Error Proportional to AVA






Area 1 x $TVI_1$ = Area 2 x $TVI_2$

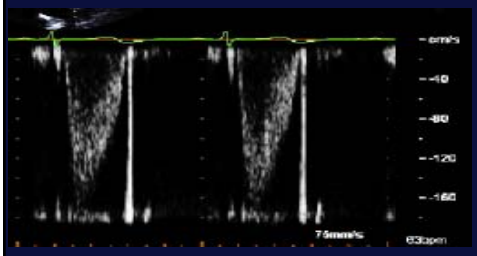
.785 ( )$^2$ x = AVA x

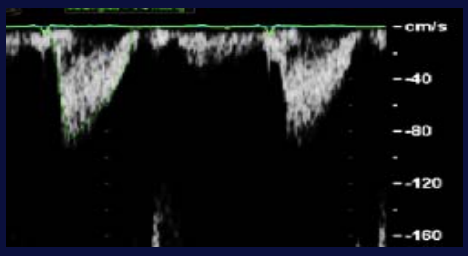
AVA = 78.8 / 98

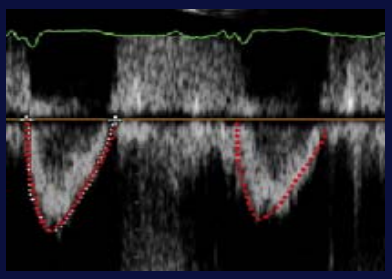
= 0.8 $cm^2$

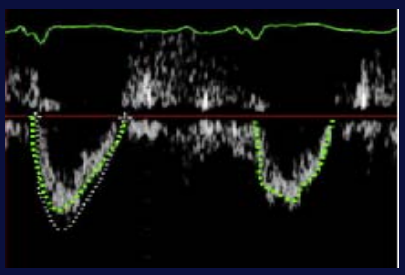
If LVOT diameter 1.8 $cm^2$ = 0.65 $cm^2$ ↓19%

# Measurement Errors: LVOT TVI Error Proportional to AVA

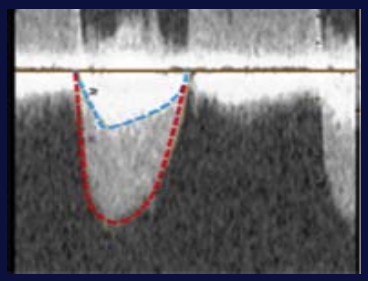


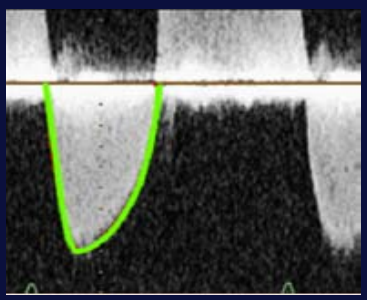


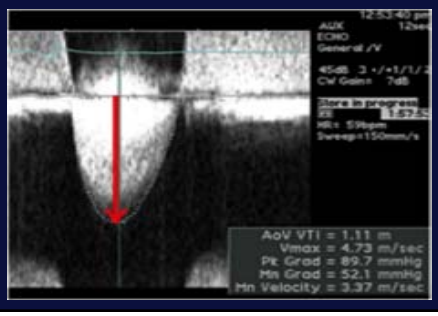



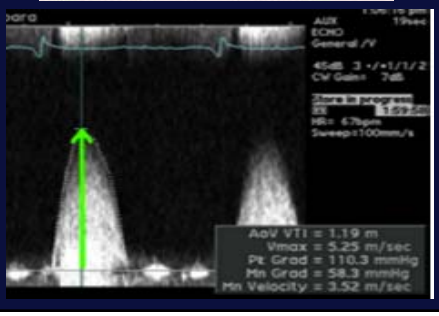


# Measurement Errors: AV VTI Error Inversely Proportional to AVA

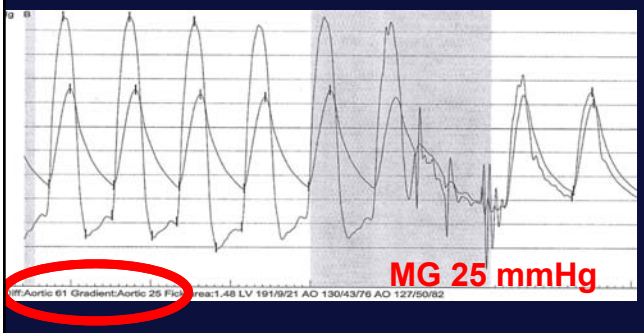


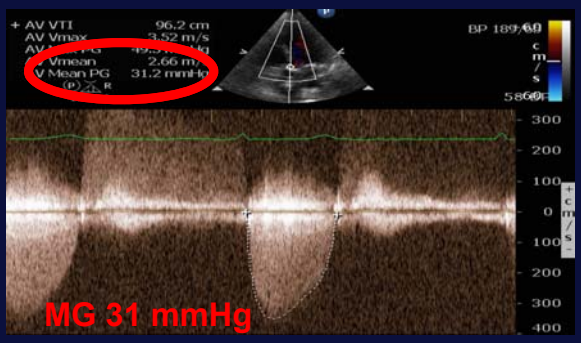




# Measurement Errors
## Catheterization and Doppler

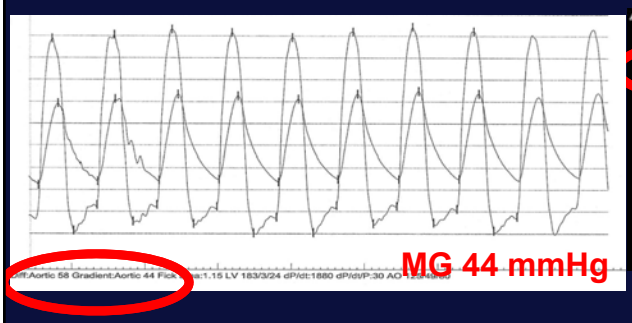


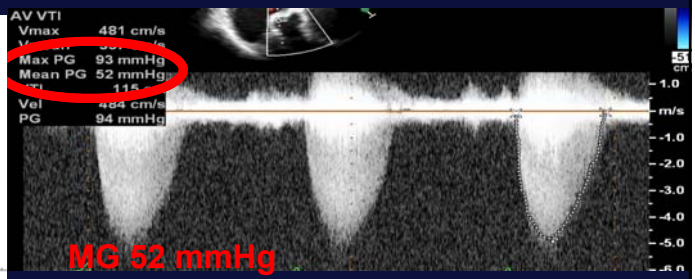




**84 Y/O NYHA III, 3/6 SEM, no S2**

# Measurement Errors
## Catheterization and Doppler

# Measurement Errors
## Catheterization and Doppler




## Assumption Errors
## MG when AVA = 1.0cm$^2$

Carabello BA. NEJM 2002;346:677-682

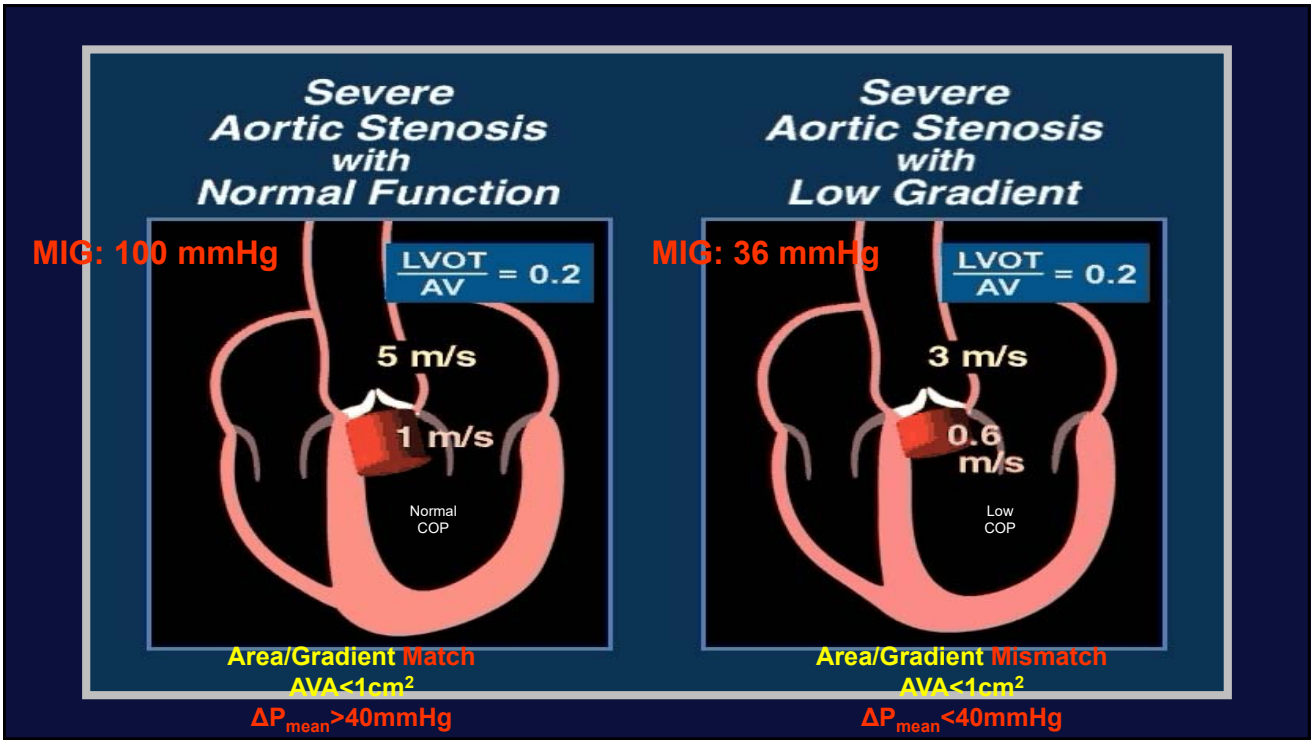
| Aortic Valve Area ($cm^2$) | Mean Gradient (mmHg) |
|---|---|
| 3.0 | 2.6 |
| 2.0 | 6.6 |
| 1.0 | 26 |
| 0.9 | 32 |
| 0.8 | 41 |
| 0.7 | 53 |
| 0.6 | 73 |

# Aortic Stenosis
## Area Gradient Mismatch

**Low flow (normal or reduced LVEF)**
**Mean Gradient <30-40mmHg**
**AVA <1.0cm²**

**True, Severe AS**

**Mild-Mod AS Low Flow (pseudo AS)**



## Aortic Stenosis
## Low Flow/Low Gradient/Low EF

**Risk Stratify**

Dobutamine Stress

Projected AVA

AV Calcium Score

Strain Imaging

## Low EF Area Gradient Mismatch

# Risk Stratify

Dobutamine Stress

# Dobutamine Echocardiography

Baseline Doppler hemodynamics

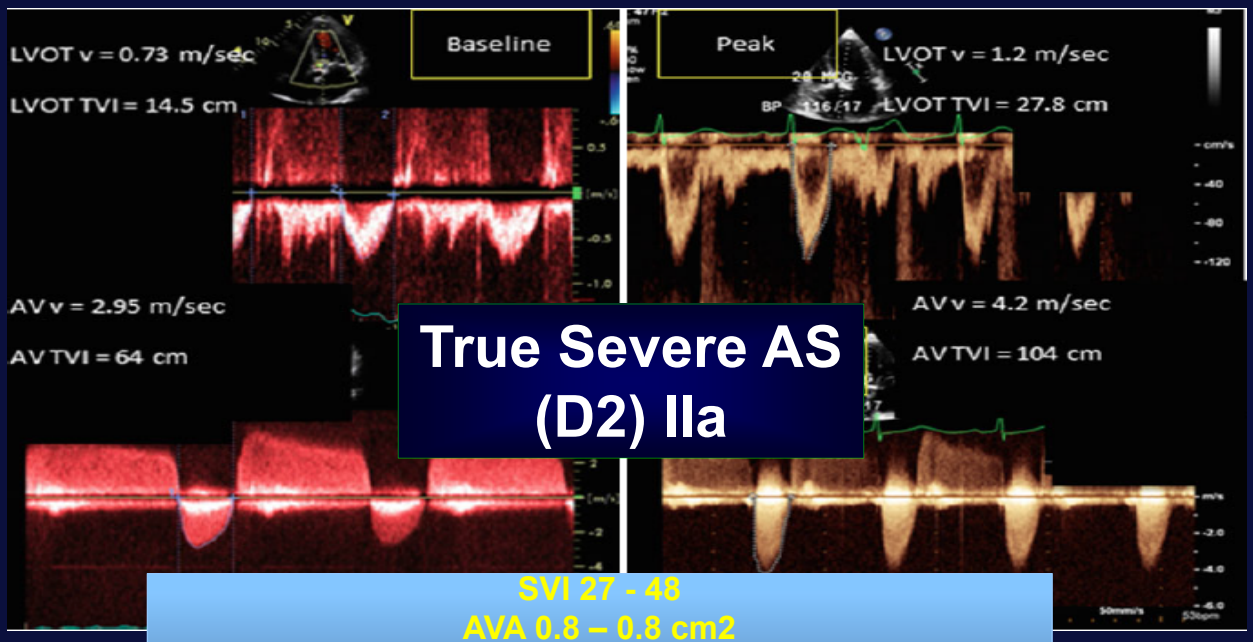
Flow Reserve? ≥ 20% SV

Vmax

Mean gradient
AV Area

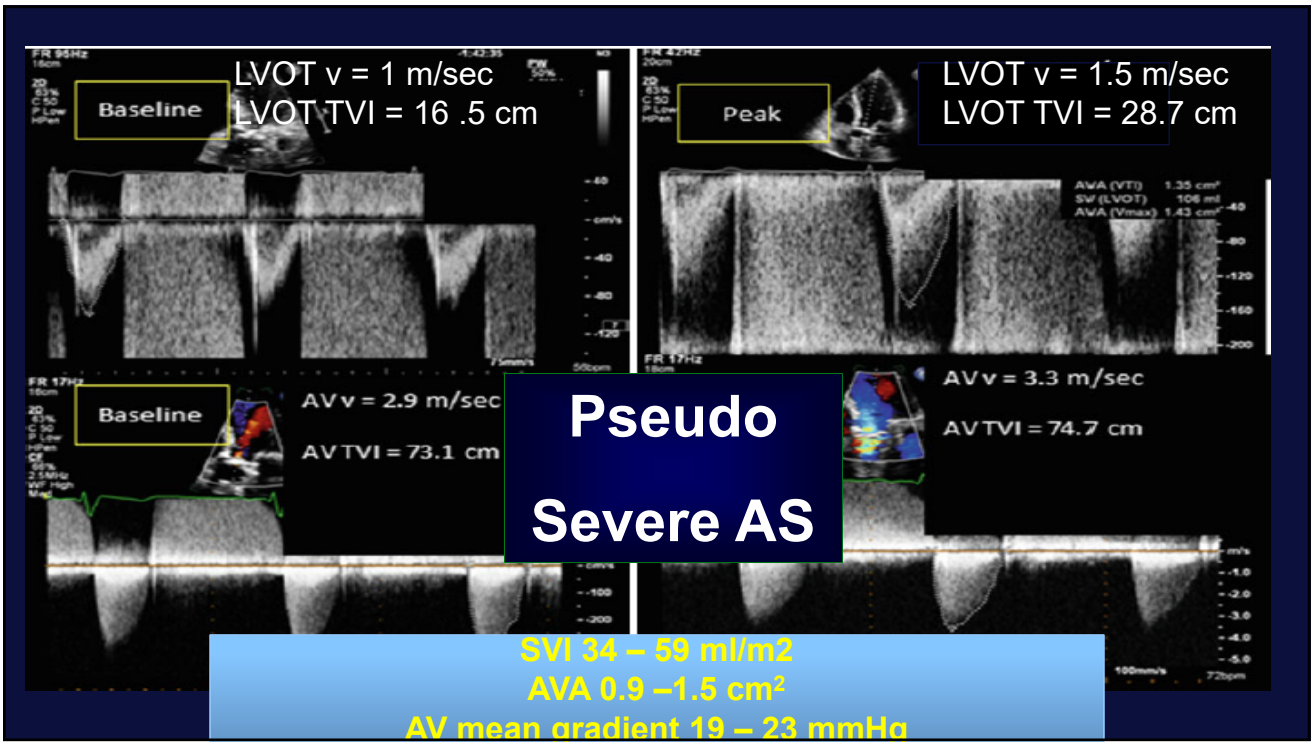
True Severe AS
(D2) IIa

Pseudo Severe AS



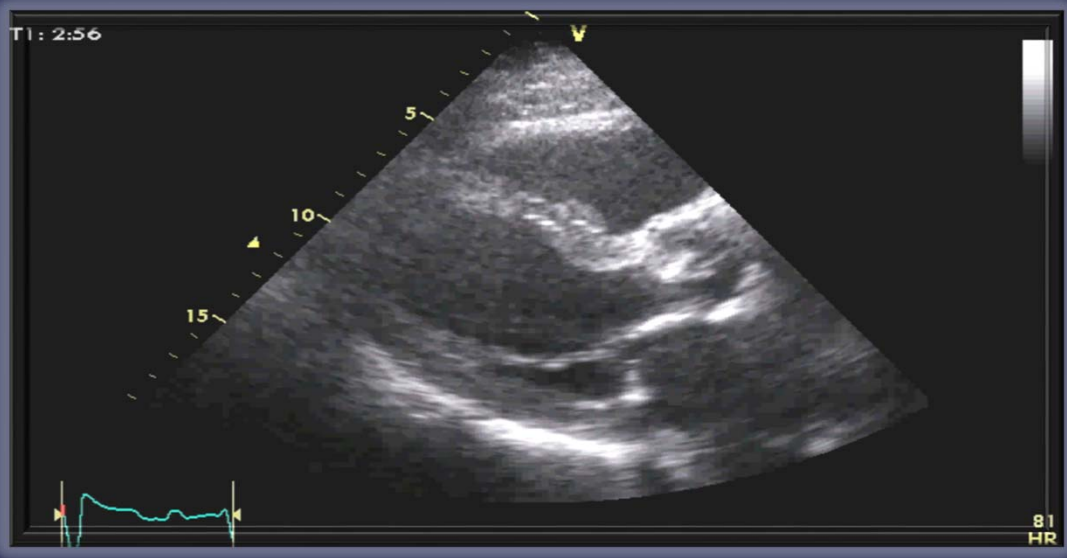

True Severe AS
(D2) IIa

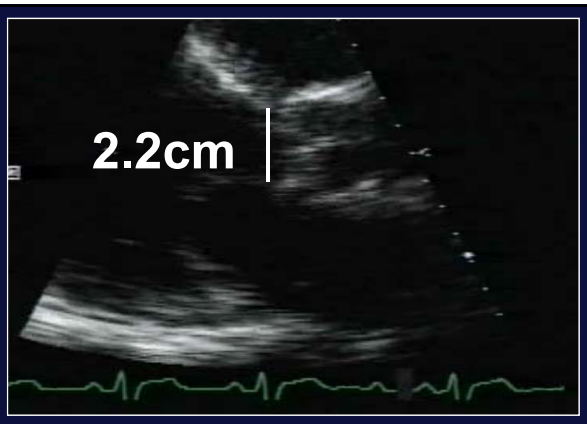
SVI 27 - 48
AVA 0.8 – 0.8 cm2
AV mean gradient 20 – 43 mmHg

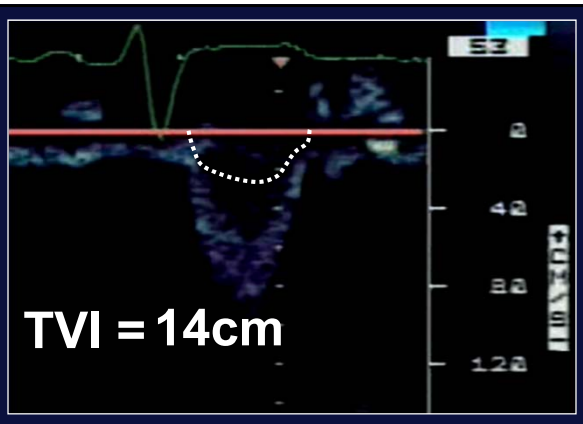



# Case

- 62 y/o male
- STEMI and subsequent CABG five years ago
- Recurrent heart failure x 3 months



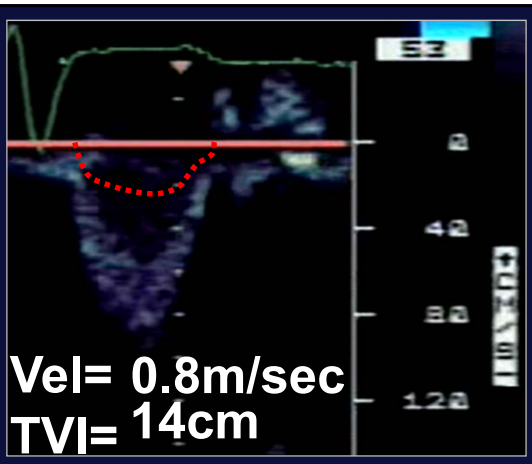



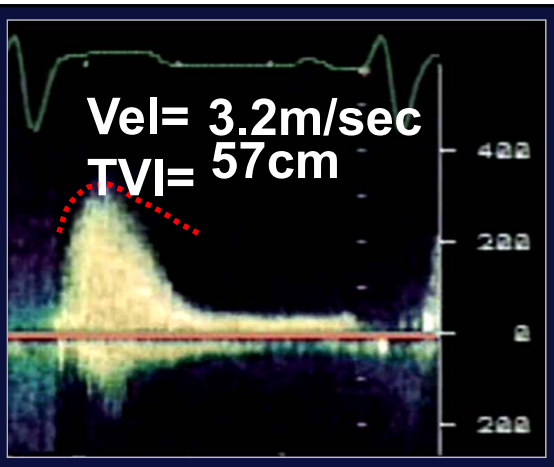




**Stroke Volume = CSA x TVI**

**= 0.785 (  )$^2$ x**

**= 53cm$^3$**

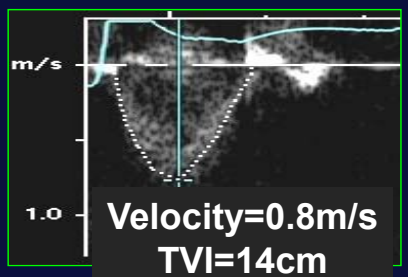



$$\text{Area}_{AV} = \frac{0.785\,(2.2\text{cm})^2 \times (\quad)}{}$$

= 0.9 cm²; MG 24mmHg

## LVOT

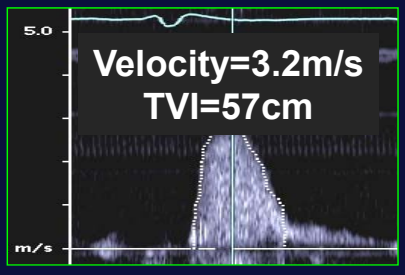



**Rest**

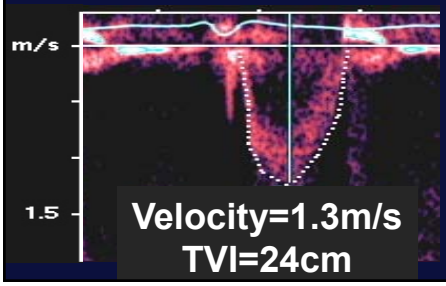
SV= 53ml

AVA=0.9cm²

## Aortic Valve




## LVOT

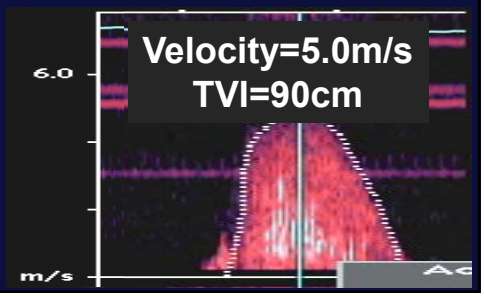



**Peak**

SV= 91ml

AVA=1.0cm²

## Aortic Valve



# Dobutamine Stress

**LV Stroke Volume**
**53– 91ml**

**Mean AV Gradient**
**24 – 52mmHg**

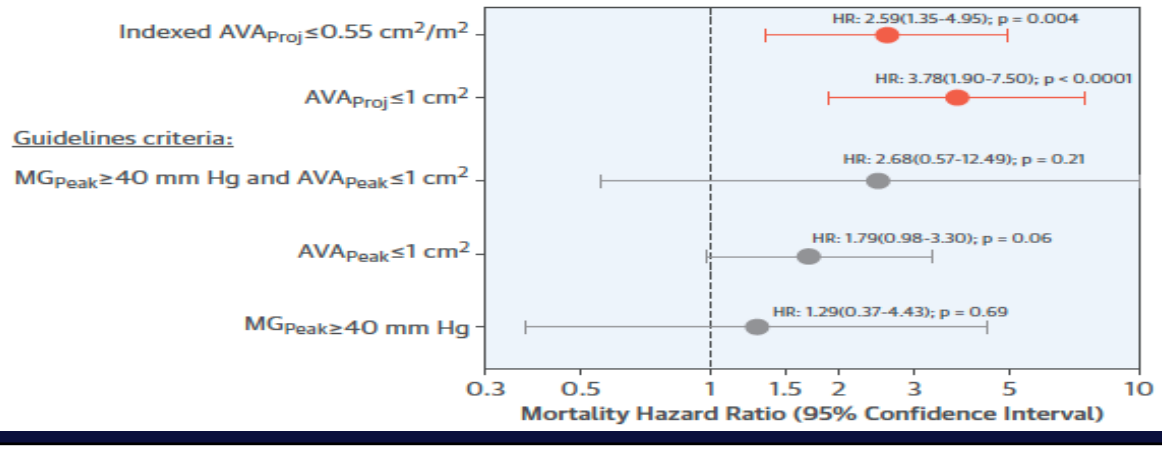
**Valve Area**
**0.9cm$^2$ – 1.0cm$^2$**

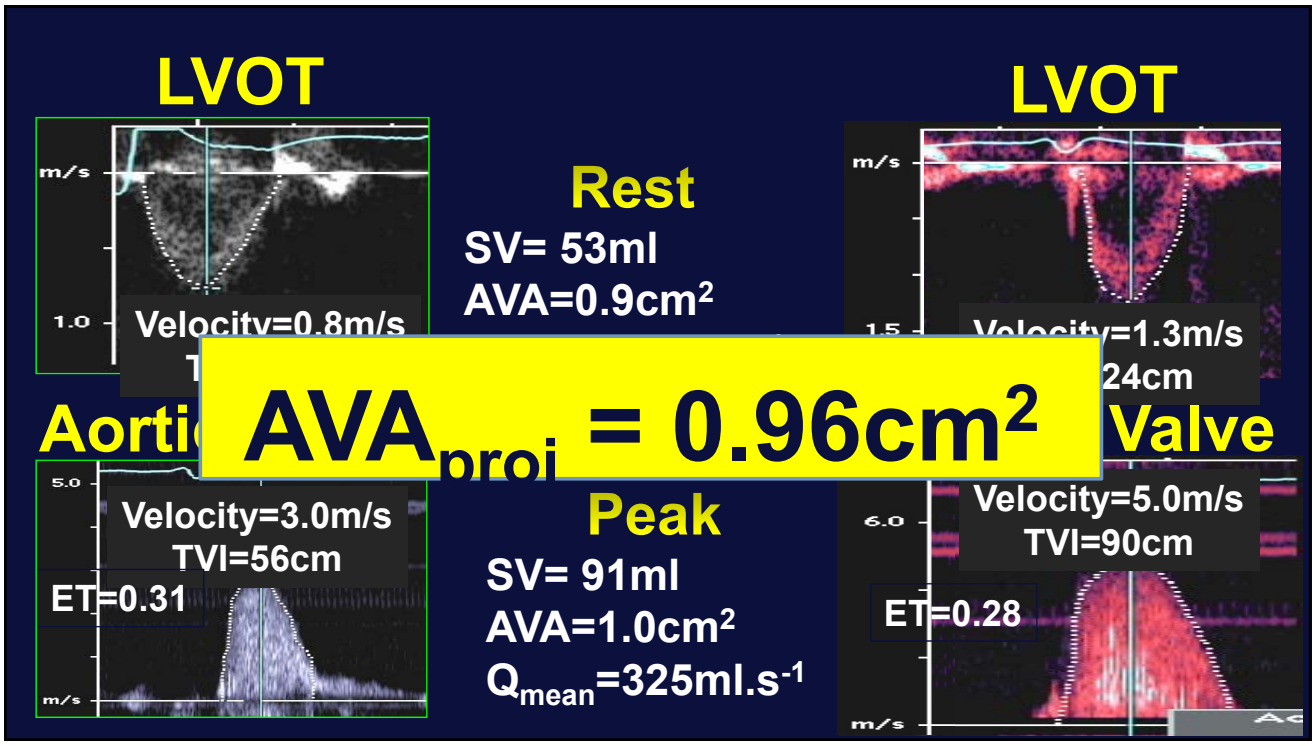
# Low EF Area Gradient Mismatch

**Risk Stratify**
**Projected AVA**

# Projected AV Area ≤ 1-1.2 cm²

## Dobutamine Stress Echocardiography for Management of Low-Flow, Low-Gradient Aortic Stenosis



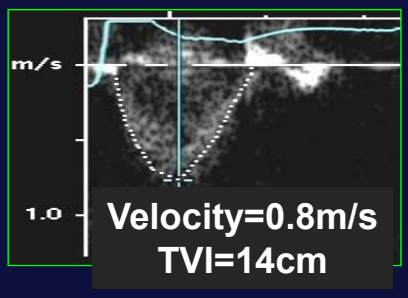



# Low EF Area Gradient Mismatch

## Risk Stratify

### Stroke Flow Rate

**LVOT**



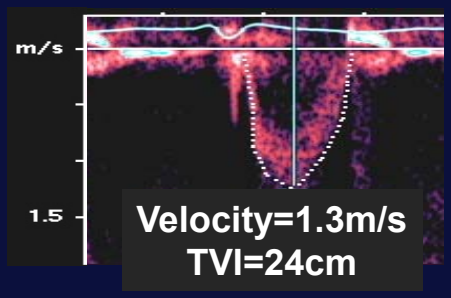

SV= 53ml

AVA=0.9cm$^2$

ET=0.31

$Q_{mean}$= 53/0.31 = 171ml.s$^{-1}$

**LVOT**




SV= 91ml

AVA=0.9cm$^2$

ET=0.28

$Q_{mean}$= 91/0.28 = 325ml.s$^{-1}$

## Resting Aortic Valve Area at Normal Transaortic Flow Rate Reflects True Valve Area in Suspected Low Gradient Severe Aortic Stenosis

Navtej S. Chahal, MBBS,*† Maria Drakopoulou, MD,* Ana M. Gonzalez-Gonzalez, MD,* Ramasamy Manivarmane, MBBS,* Rajdeep Khattar, MBBS,*† Roxy Senior, MD*†‡

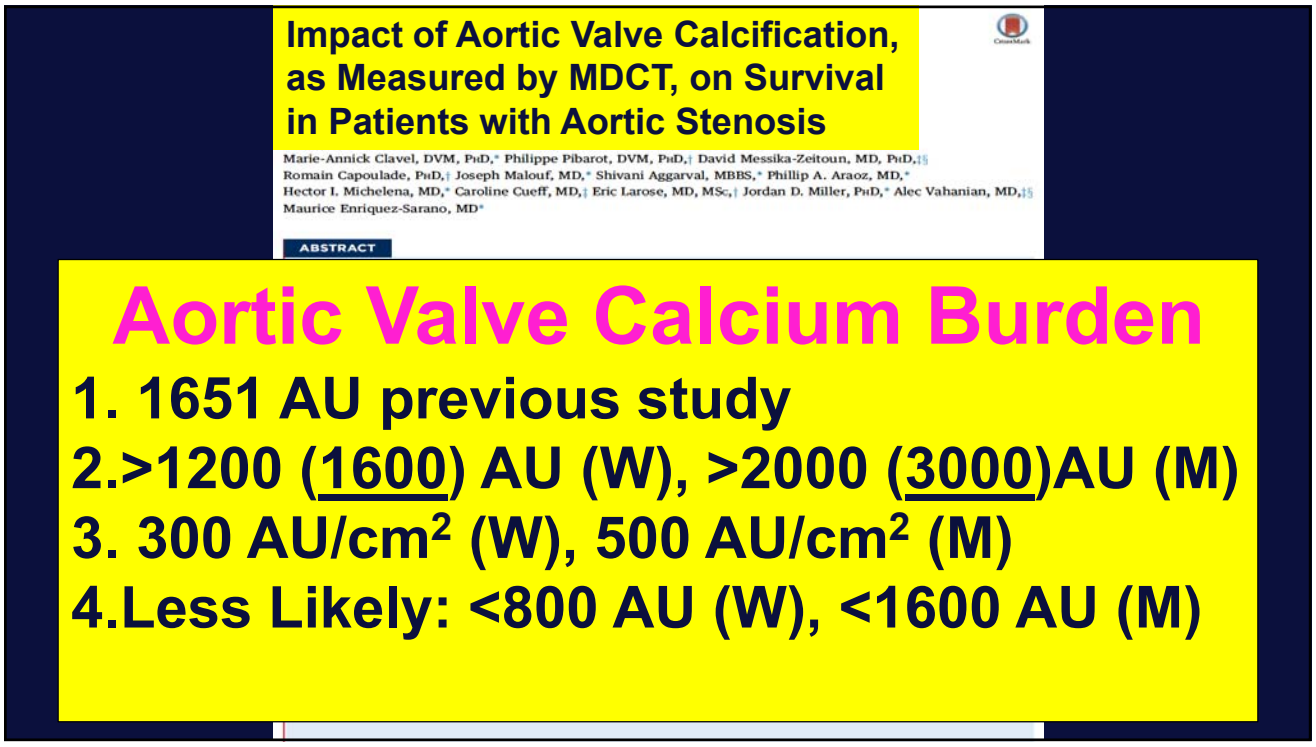
| | n | Rest AVA, $cm^2$ | Stress AVA, $cm^2$ | p value |
|---|---|---|---|---|
| Q < 200 ml/s | 48 | 0.74±0.12 | 0.89±0.25 | <0.001 |
| Q ≥ 200 ml/s | 19 | 0.85±0.09 | 0.89±0.12 | 0.19 |

**Interpretation: If normal resting flow rate, the corresponding AVA is likely to be represent the true hemodynamic severity of the stenosis and further "flow correction" with SECHO is not likely required.**

J Am Coll Cardiol Img 2015

# Aortic Stenosis
# Low Flow/Low Gradient/Low EF

## Risk Stratify
## AV Calcium Score




# Aortic Stenosis

## Low Flow/Low Gradient/Low EF

## Risk Stratify

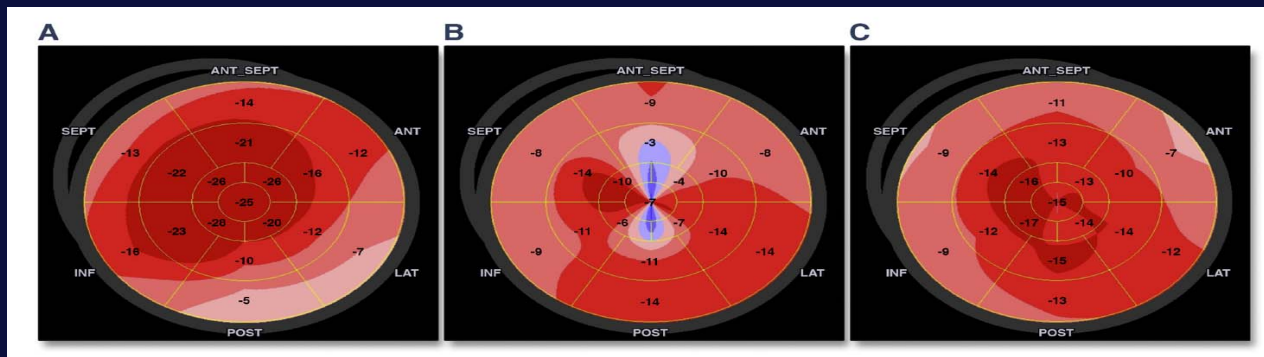
## Strain Imaging

## LV Mechanics in Mitral and Aortic Valve Diseases

### Value of Functional Assessment Beyond Ejection Fraction

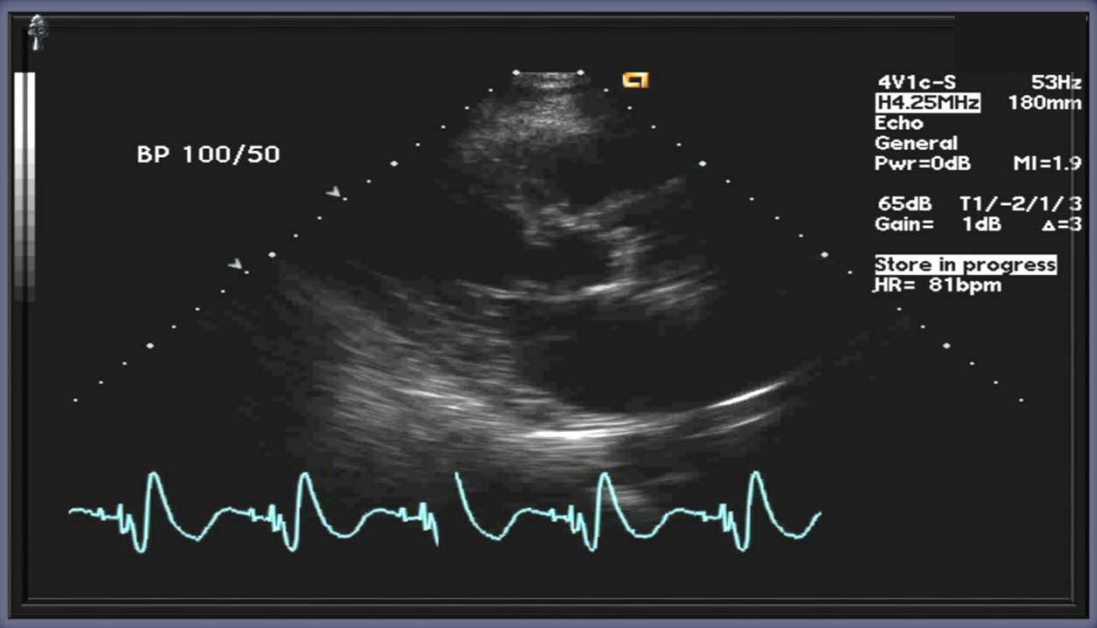
J Am Coll Cardiol Img 2014;7:1151-66

Elena Galli, MD, PhD,* Patrizio Lancellotti, MD, PhD,† Partho P. Sengupta, MD, DM,‡ Erwan Donal, MD, PhD*




# Case

- 75 year old male
- Presents with dyspnea and syncope
- HTN (treated BP 150/75)
- Grade III/VI mid peaking systolic murmur LSB



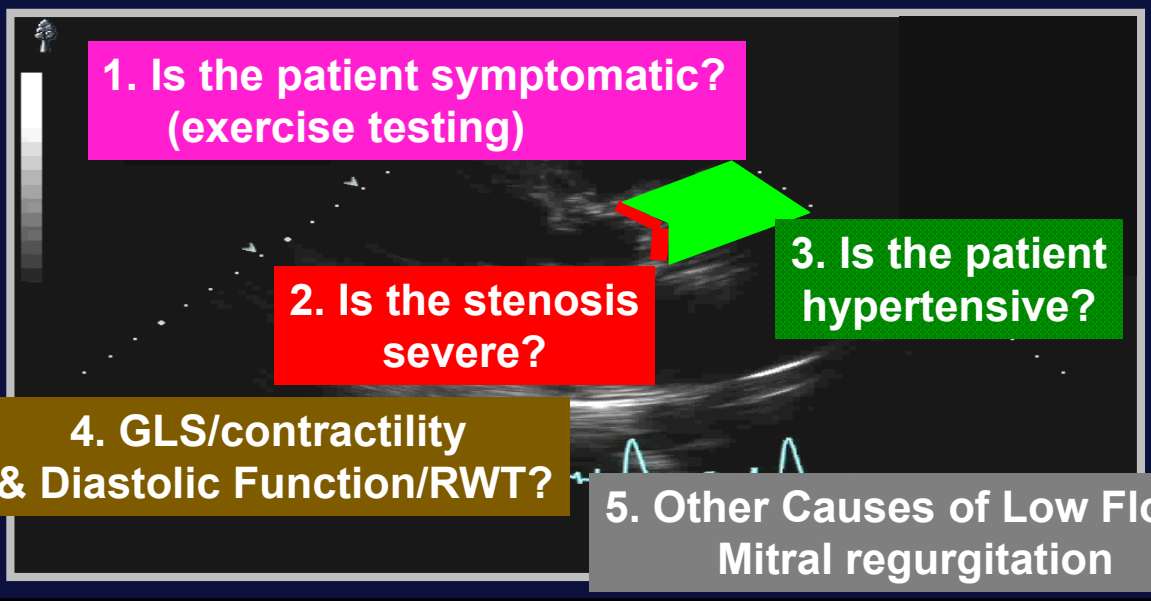

## Echocardiography
## Normal EF Area Gradient Mismatch

- LVEF 55%
- AV Mean G 26mmHg
- AVA 0.8cm$^2$
- AVA index 0.45cm$^2$/m$^2$
- LVEDV 88ml
- SVi 32 ml/m$^2$

# Flow Versus EF

- So why is the Flow Low?
  - Preload: Small LV volume (LVH)
  - Contractility: Despite EF normal, contractility (&EF) impaired for degree of LVH
  - Afterload: Global LV afterload (Valve and Vascular)

# Approach to Patients with Normal EF Area Gradient Mismatch



# Aortic Stenosis

## Low Flow/Low Gradient/NL EF

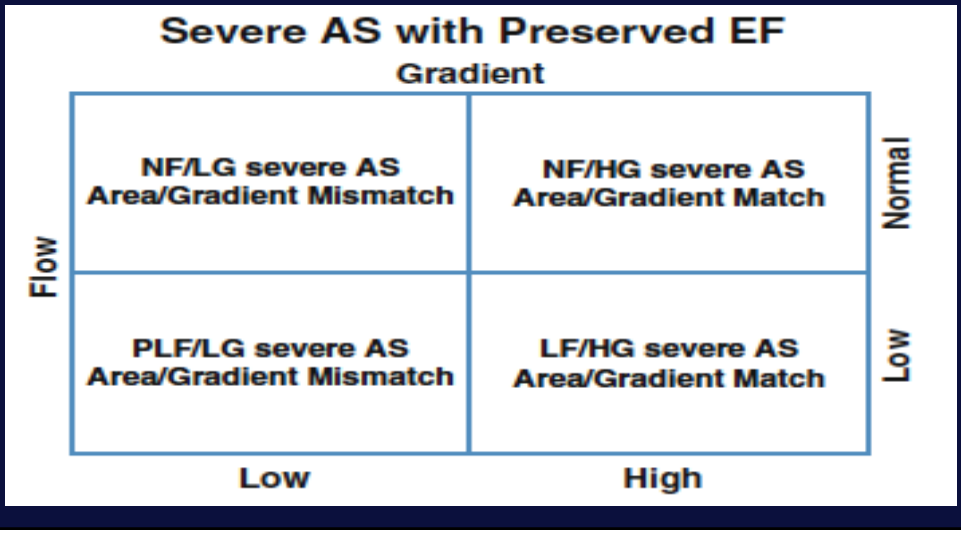
# Risk Stratify

## AV Calcium Score

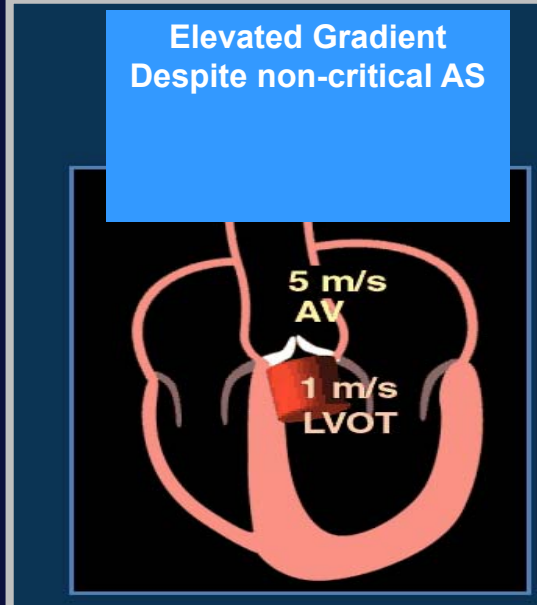
## Strain Imaging

## Stroke Flow Rate

# Novel Classification of AS with Normal EF



# Aortic Stenosis
## Reverse Area/Gradient Mismatch




**Reverse Area/Gradient Mismatch**

**AVA>1cm²**

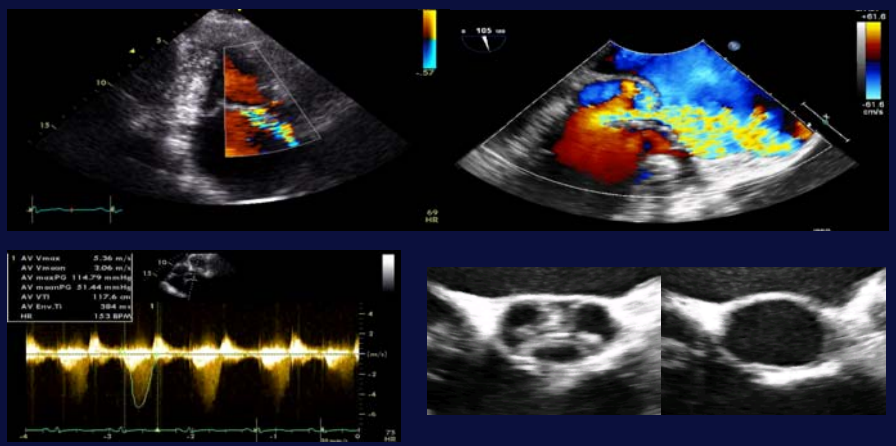
**$\Delta P_{mean}$>40mmHg**

Courtesy Heidi Connolly

# Causes of Reverse A/G Mismatch

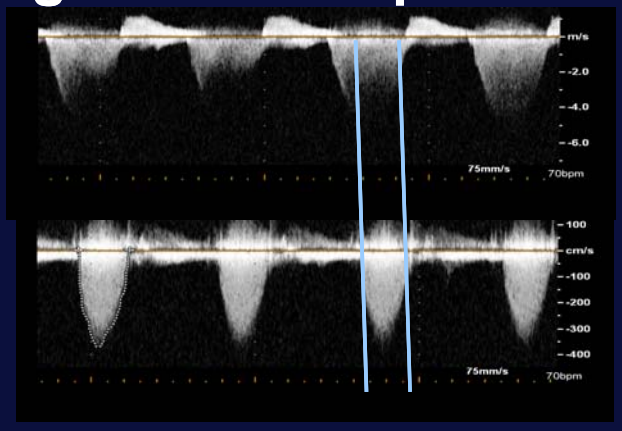
- Errors of Measurement
- High Flow
- Pressure recovery
- Eccentric Jet
- Para-valvular Obstruction
- Prosthetic-valve specific

# Errors of Measurements
# Eccentric Mitral

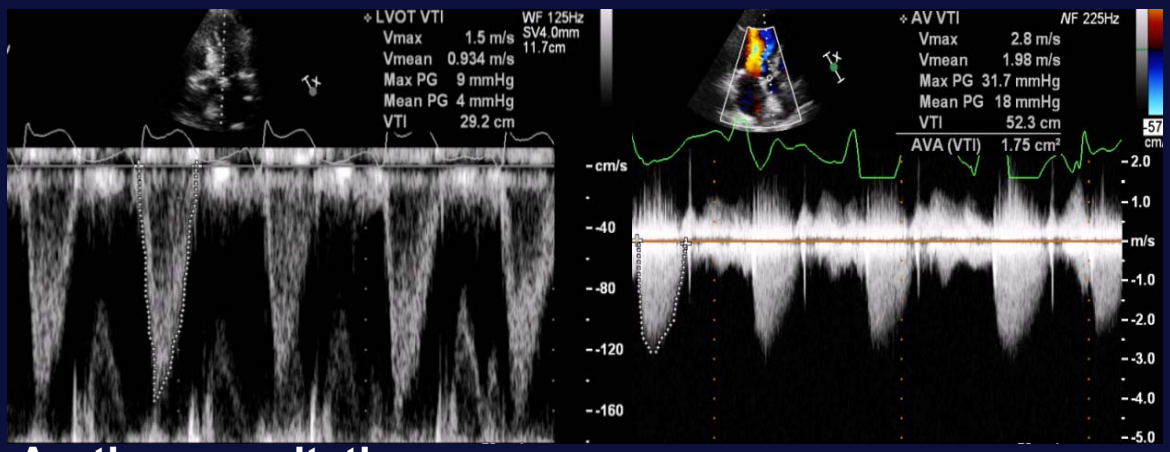


# Mitral Regurgitant Jet Versus Aortic Stenosis Jet

- Mitral regurgitation occupies IVC and IVR




# High Flow




- Aortic regurgitation
- Hyperdynamic states (dialysis, anemia)
- Dimensionless Index

B

# Pressure Recovery

*Doppler*

Pmean = 34 mmHg

EOA = 0.6 $cm^2$

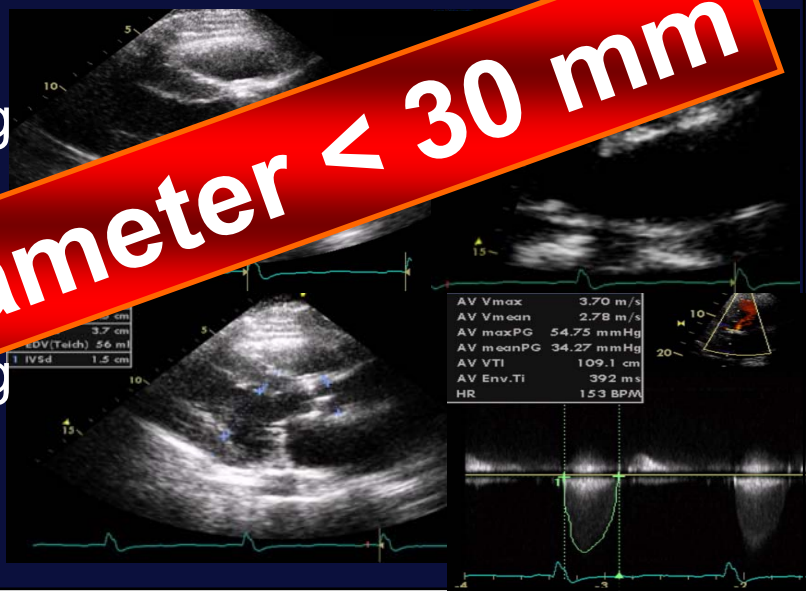
*Catheter*

[illegible] mmHg

[illegible] $cm^2$

APR= 34-18 = 16

**Aortic Diameter < 30 mm**




## Energy Loss Index

- **Energy loss Co-efficient**

  **ELCo = $\frac{AVA \times AAa}{AAa - AVA}$**

- **AVA = aortic valve area, AAa = aortic area**
- **Energy loss index: ELCo/BSA**
- **ELI < 0.52-0.76 $cm^2$ has poor outcomes and severe AS**
- **More significant with increase flow and moderate aortic stenosis**

B

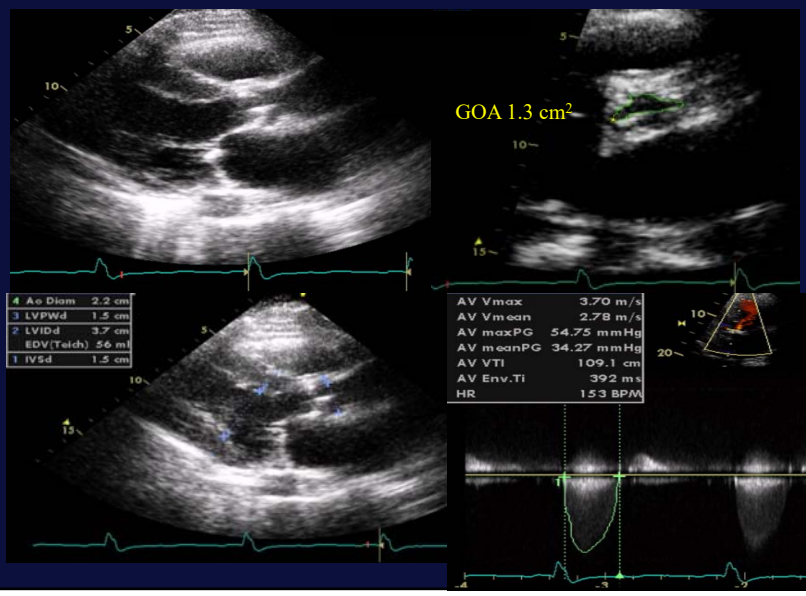
# Pressure Recovery/High Flow

EOA = 0.6 $cm^2$

AAd = 2.2 cm

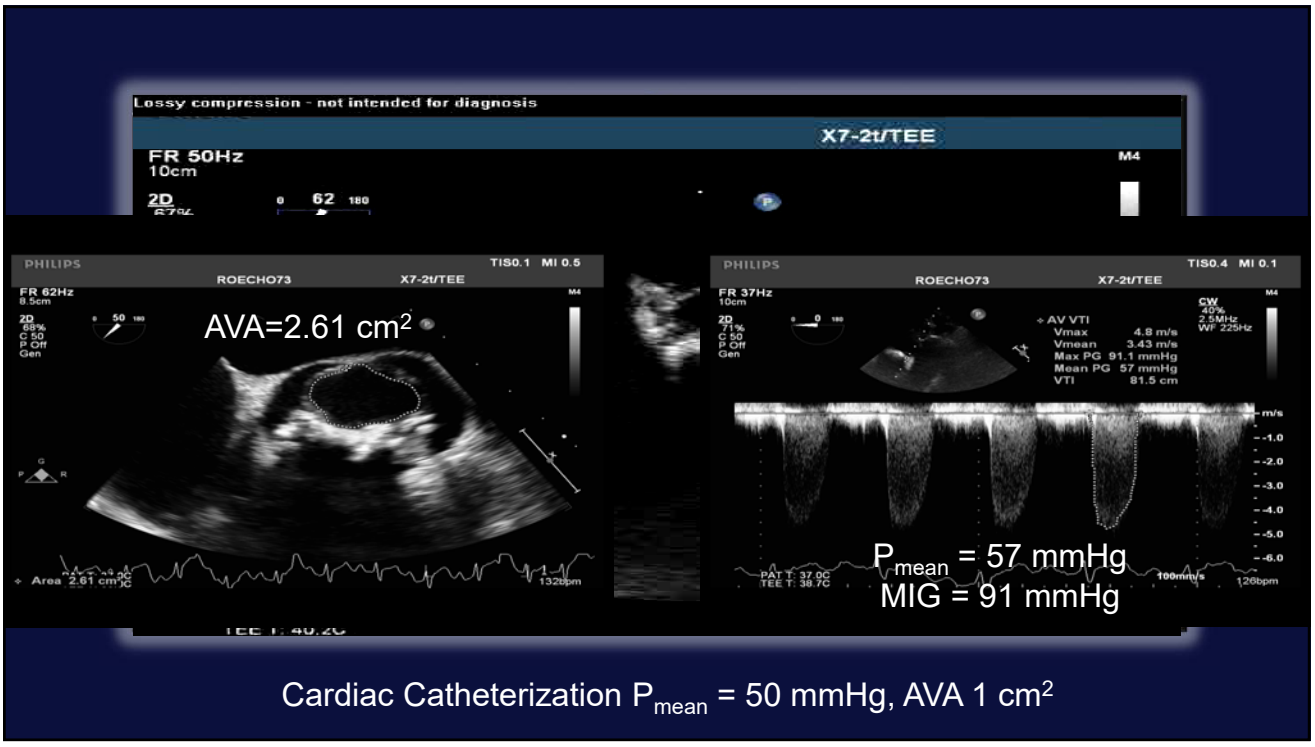
AAa = 3.8 $cm^2$

ElCo = 3.8x0.6/3.8-0.6



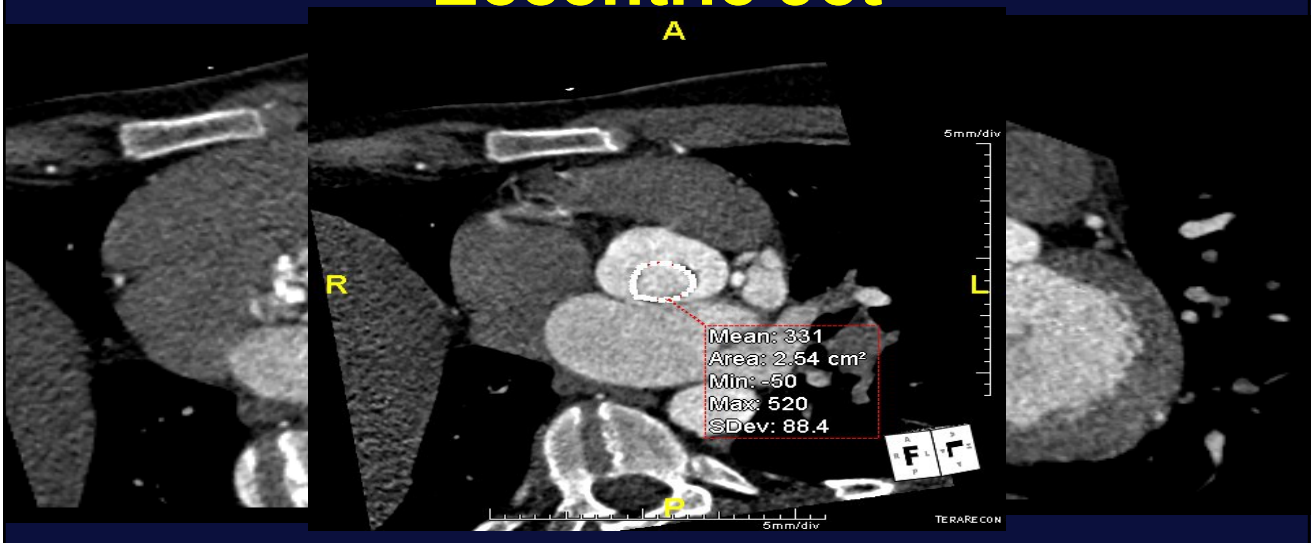

# Eccentric Jet

- Case:
- 29 y/o male
- Carries a diagnosis of Asymptomatic severe AS
- Quit Law School

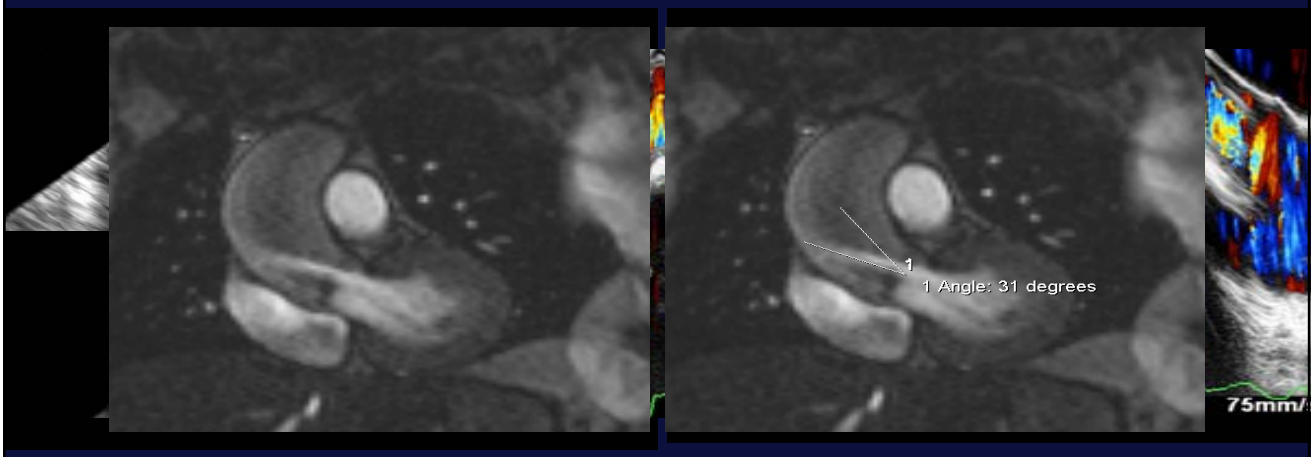



Cardiac Catheterization $P_{mean}$ = 50 mmHg, AVA 1 $cm^2$

# Eccentric Jet



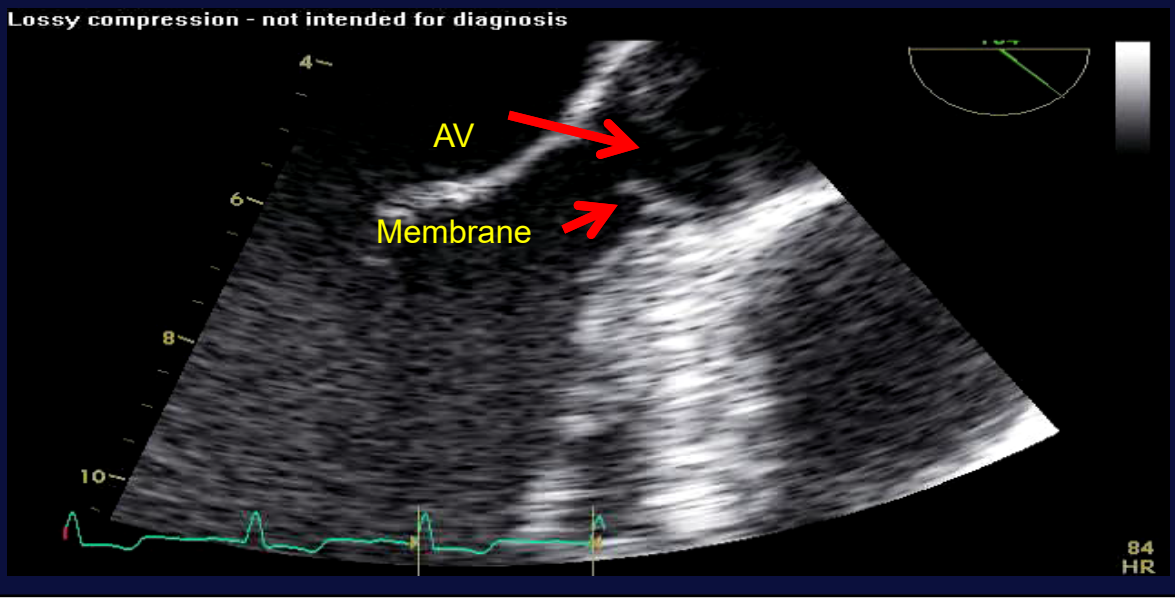
# Eccentric Jet: Echo



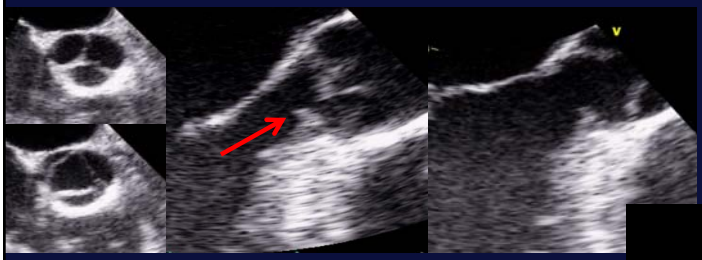

# Para-valvular Obstruction

- Sub-Aortic membrane
- Hypertrophic Obstructive Cardiomyopathy
- Supravalvular Obstruction
- Mitral valve Prosthesis

# Sub-Aortic Membrane




# Sub-Aortic Membrane



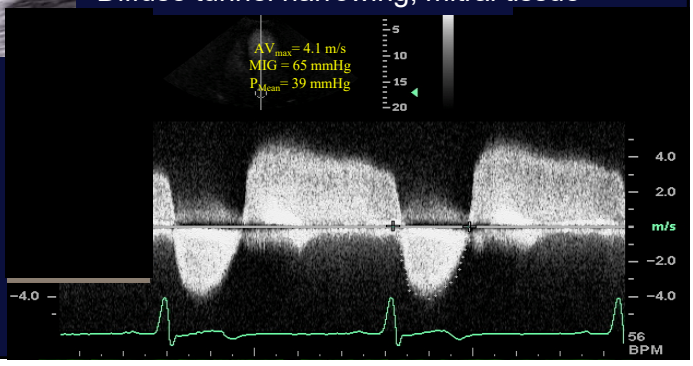
Progressive Disease
Other congenital anomalies in 50%
- VSD/PDA/Coarctation
- Shone's Complex
- Bicuspid AV
- leftsided-SVC

B

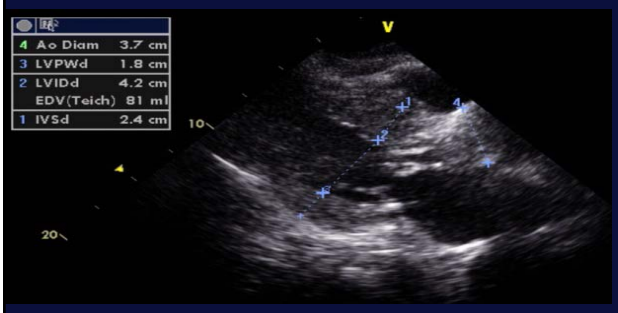
Types: Membrane, fibromuscular ridge, Diffuse tunnel narrowing, mitral tissue

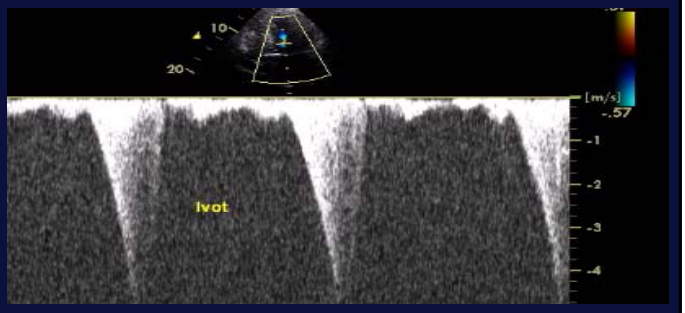
May Cause aortic regurgitation
Treatment: Surgery
No symptoms: Catheter LVOT-A peak/Doppler Mean = 50 mmHg
Symptoms: Catheter LVOT-A peak/Doppler Mean = 30-50 mmHg
Adults may use Doppler Peak > 50 mmHg
Resection/Konno procedure

B



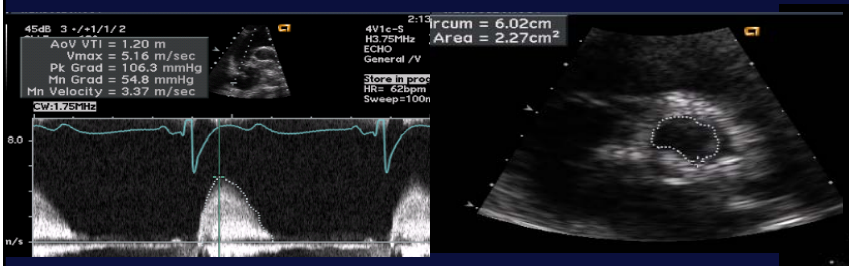
# Hypertrophic Obstructive Cardiomyopathy

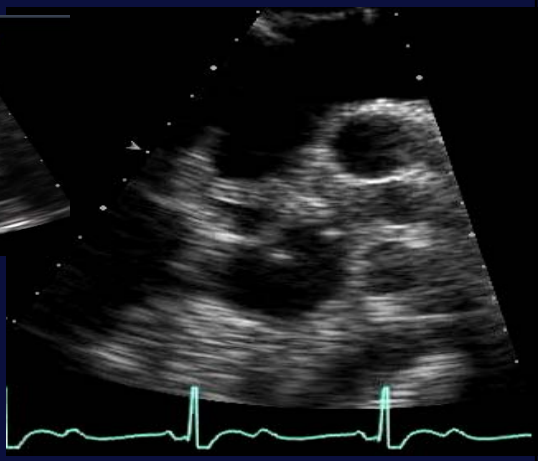



Alcohol Septal Ablation or Surgery
High Risk features
ICD

# Supra-Aortic Obstruction



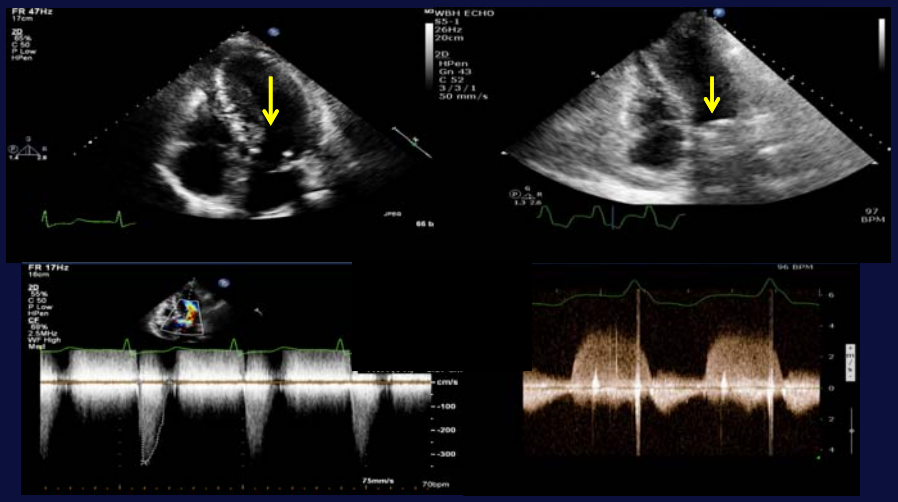



Non-Familial Sporadic
William syndrome:
- Elfin Facial
- Hypercalcemia
- Behavioral
- Diagnosed by CVS and fetal echo

B

Familial Sporadic
Coronary anomalies
Types: Hour glass, Membrane, Diffuse narrowing: Surgery

# Obstruction by Mitral Valve Prosthesis



# Take Home Message
## Severe Aortic Stenosis
### Multimodality Approach

- In addition to AVA and $\Delta P_{mean}$

  **Flow** SVI < 35 ml/m$^2$, Flow rate < 200 ml/s

  **Flow** eccentricity

  **Pressure Recovery/ AV morphology**

- Think of **global afterload** in AS to the LV: Mixed AV disease/HTN **regardless of symptoms**
- Area and Gradient may **not match**
- Echo/Cath/AV morphology provide **complimentary NOT identical** data

# CONCLUSIONS

- For a given AV GOA
  - The Gradient can be variable
  - The EOA can be variable
  - (Derived from gradient)
  - The Area and Gradient may not match
  - The Doppler and Catheter measures may not match

THANK YOU